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Drilling Waste Disposal - General Document

Heritage Fund

Alberta

CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Conservation and Reclamation Council. The Council Chairman is from Alberta Environmental Protection. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). Committee members represent the Alberta Departments of Agriculture, Food and Rural Development, Energy, and Environmental Protection, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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REPORT #
RRTAC 93-5

Drilling Waste Disposal - General Document

by

T.M. Macyk and S.A. Abboud

Alberta Research Council

Prepared for

Oil and Gas Reclamation Research Program

ALBERTA CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1993

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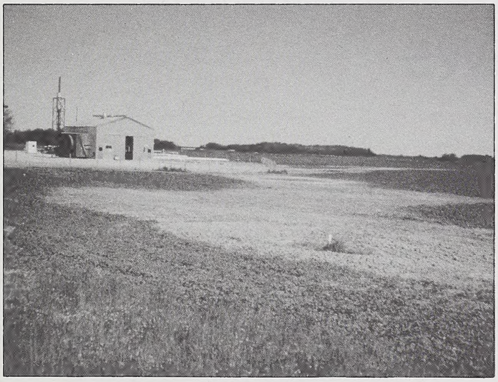

Members: Chris Powter (Chairman) - Alberta Environmental Protection; Roger Creasy - Energy Resources Conservation Board; Emil Dombroski - Alberta Environmental Centre; Al Fedkenheuer - NOVA Corporation of Alberta; Jim Fujikawa - Alberta Environmental Protection; Arnold Janz - Alberta Environmental Protection; Alan Kennedy - Imperial Oil; Leon Marciak - Alberta Agriculture and Rural Development; Doug Mead - Shell Canada Resources Limited; Sam Takyi - Alberta Environmental Protection; Wayne Tedder - Alberta Agriculture, Food and Rural Development; Bill Wolff - Bisset Resource Consultants.

DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Conservation and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

RRTAC contracted the Alberta Research Council to produce this document to provide more information on disposal using the methods described in Guide G-50, including detailed calculations for disposal rates and examples. Guide G-50: Drilling Waste Management (ERCB 1993) provides guidelines for disposal of drilling wastes. Criteria for the most common methods of disposal, mix-bury-and-cover and landspreading, are covered in detail in the Guide. However, industry is encouraged to continue to investigate alternative disposal technologies that will provide even greater environmental protection.

REVIEWS

This report was reviewed by members of RRTAC and the Oil and Gas Reclamation Research Program Committee.

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1. INTRODUCTION

The environmental impact of land-based drilling waste disposal can be minimized by following a recommended set of procedures, beginning with sump location evaluation and concluding with the ultimate disposal and associated reclamation activities.

Land-based treatment and disposal procedures represent the final step in a series whereby all efforts to reduce, recycle, and reuse the waste material have been undertaken. Land-based treatment and disposal technology is based on the premise that the waste will be applied to the plant-soil-water system at such rates or over such limited time spans that no land is irreversibly removed from some other potential societal use. Operators must carefully evaluate the potential effects of their disposal practices in light of the final reclamation objectives and assessment criteria of the Land Conservation and Reclamation Council (Alberta Environmental Protection 1992).

This document represents a revision and update of a document entitled "A Field Manual for the Management and Disposal of Drilling Wastes" which was circulated for review in July, 1990. The above mentioned documents also represent a revision and update of the field manual entitled "Disposal of Wastes from Drilling Systems on the Public and Private Lands of Alberta" published as part of Alberta Land Conservation and Reclamation Council Report No. RRTAC 87-1 "Disposal of Drilling Wastes". the "document package" prepared is comprised of three entities.

1. Drilling Waste Disposal in Alberta - General Document
2. A Field Manual for Drilling Waste Disposal in Alberta
3. A Computer Program for Drilling Waste Disposal in Alberta

This document package was prepared to assist industry and government staff in the planning and implementation of environmentally sound methods for disposal of drilling wastes.

The work associated with preparation of this document was coordinated with the activities of the joint government/industry Drilling Waste Review Committee whose objective was to update the Energy Resources Conservation Board (ERCB) (1975) drilling waste disposal guidelines. Input regarding the preparation of the manual was sought from staff members of government agencies and industry, particularly field staff.

This "general" document provides an overall perspective and description of the steps involved in the management and land-based disposal of drilling wastes in Alberta (Figure 1). The field manual is provided primarily for use by field staff. The computer program was developed to assist with the calculations associated with the planning for disposal of drilling wastes according to the criteria and guidelines defined for Alberta (ERCB 1993).

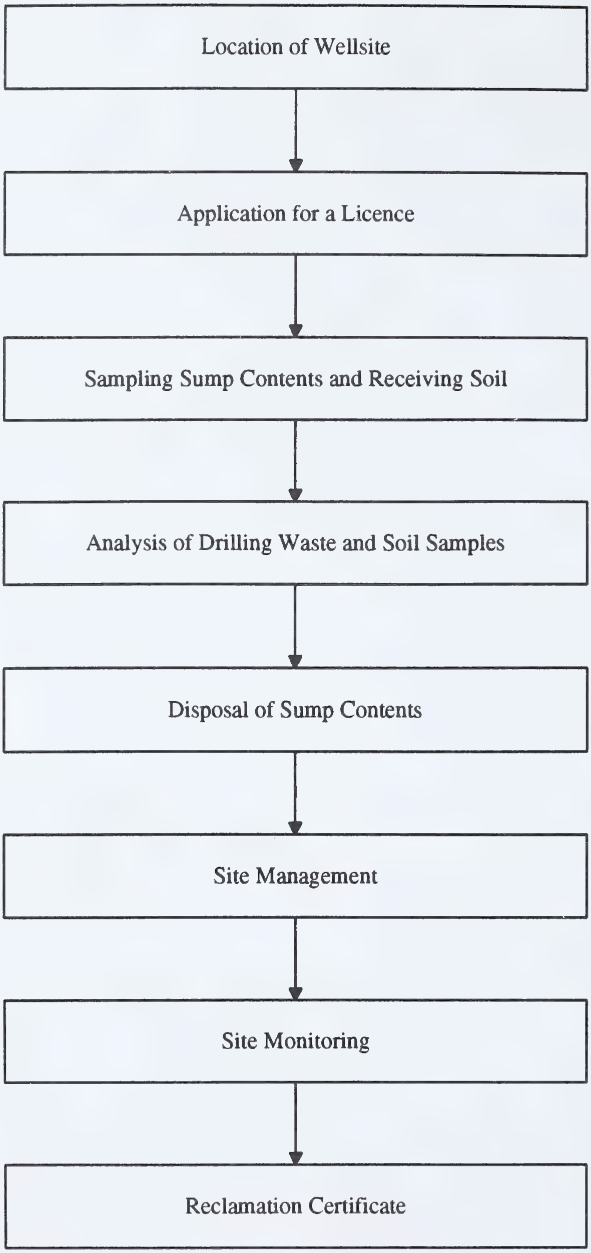
Location of Wellsite
Application for a Licence
Sampling Sump Contents and Receiving Soil
Analysis of Drilling Waste and Soil Samples
Disposal of Sump Contents
Site Management
Site Monitoring
Reclamation Certificate

Figure 1. Steps in the management and land-based disposal of drilling wastes.

2. BACKGROUND

2.1 FUNCTIONS OF DRILLING FLUIDS

Drilling fluids perform the following very important functions in the drilling process (United Nations Environment Programme 1985).

1. Remove drilled cuttings (solids) from the hole and carry them to the surface.
2. Lubricate the drill bit and string.
3. Deposit an impermeable cake on the well bore wall to seal the formations being drilled so:
    a) contaminants do not enter the mud
    b) the fluid phase of the mud does not enter the formation.
4. Control downhole pressures.
5. Suspend drill cuttings in the fluid when circulation is interrupted.
6. Support part of the weight of the drill bit and string.

2.2 DRILLING MUD TYPES

The major drilling mud systems commonly used in Alberta include:

1. water-based muds;
2. salt-based muds; and,
3. oil-based muds.

The following discussion regarding the various mud types is based on personal communication with a number of individuals as well as information obtained during the completion of the Drilling Waste Sump Chemistry Study (Macyk et al. 1993) and the Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta (Macyk et al. 1989).

A detailed description of major components, applications and regional distribution of the most commonly used systems, as well as major additives are provided in the RRTAC 87-1 publication entitled "Disposal of Drilling Wastes" by Leskiw et al. (1987). In addition, a detailed assessment of the regional distribution of mud systems used in Alberta and their characteristics is described in Macyk et al. (1993).

The following description of mud systems is based largely on information contained in World Oil (1991).

2.2.1 Water-Based Muds

Freshwater or clear muds are generally the cheapest and most frequently used mud systems. They are used when major problems such as excessive pressures, temperatures and salinity or water sensitive formations are not anticipated. Water-based mud systems account for more than 80% of the systems used for drilling in Alberta (Macyk and Abboud 1990; Macyk et al. 1993).

Non-dispersed mud systems which may consist of natural muds and other lightly treated systems are generally used for shallow wells or top hole drilling. Dispersed muds are commonly used at greater depths or where hole conditions may present problems. Ligno-sulfonates or other products are used as dispersing agents.

Calcium treated systems are usually comprised of hydrated lime, gypsum and calcium chloride. These muds are used to control sloughing shale, hole enlargement and to prevent formation damage. Polymer muds, which are generally comprised of long-chain, high molecular-weight chemicals, are effective in flocculating muds, increasing viscosity, reducing filtrate loss and stabilizing the formation.

Saturated salt mud systems usually have a chloride ion concentration ranging from about 5000 to 190 000 ppm. These muds are prepared by adding potassium chloride (KCl) or sodium chloride (NaCl) to water. The KCl muds are commonly used for drilling through unstable shales and other formations where permeability damage by fresh water could potentially occur. The NaCl muds are generally used for drilling salt domes or salt sections of a hole. The NaCl systems are not commonly used and comprised less than 2 percent of the sumps sampled in 1990 under the auspices of the Drilling Waste Review Committee Sump Chemistry Study (Macyk et al. 1993).

Ammonium sulphate and diammonium phosphate (DAP) muds consist of a water phase saturated with ammonium sulphate or diammonium phosphate.

2.2.2 Oil-Based Muds

Oil-based fluids are used for a number of applications such as high temperature concerns, problems related to torque and drag in deep wells, wells where sticking and hole stabilization is a problem and other situations. Invert emulsion muds are water-in-oil fluids and have water as the dispersed phase and oil as the continuous phase. They may contain up to 50% water in the liquid phase.

Oil-based muds are usually made from a mixture of oxidized asphalts, organic acids, various other agents and diesel fuel. Industry is actively seeking alternative oil-based mud systems including mineral oils derived from vegetable sources.

2.2.3 Other Systems

Four basic systems are included in this category. Dry air drilling involves injecting dry air or gas into the wellbore at rates capable of achieving annular velocities that will remove cuttings. Mist drilling involves injecting a foaming agent into the air stream which mixes with produced water and separates and lifts drill cuttings.

Stable foam uses chemical detergents and polymers and a foam generator carries cuttings in a fast-moving air stream. Aerated fluids rely on mud with injected air which reduces hydrostatic head to remove drilled solids from the wellbore.

2.2.4 Mud Additives

Additives are used in conjunction with the drilling muds to achieve required mud properties. Some of the additives have multiple uses. A list of the commonly used additives and their function(s) are provided below (World Oil 1991).

1. **Alkalinity, pH control additives** - products designed to control the degree of acidity or alkalinity of a

fluid. While providing benefits to drilling some additives may pose some problems for disposal in the environment. These can include lime, caustic soda and bicarbonate of soda.

2. **Bactericides.** Used to reduce bacteria count. Paraformaldehyde, caustic soda, lime and starch preservatives are commonly used.
3. **Calcium removers.** Caustic soda, soda ash, bicarbonate of soda and certain polyphosphates make up the majority of chemicals designed to prevent and overcome the contaminating effects of anhydrite and gypsum, both forms of calcium sulfates.
4. **Corrosion inhibitors.** Hydrated lime and amine salts are often added in systems to check corrosion. A good fluid containing an adequate percentage of colloids, certain emulsion muds and oil muds should exhibit excellent corrosion inhibiting properties.
5. **Defoamers.** Products designed to reduce foaming action, particularly in brackish and saturated saltwater muds.
6. **Emulsifiers.** For creating a heterogeneous mixture of two liquids. These include modified ligno-sulfonates, certain surface active agents, anionic and nonionic (negatively charged and noncharged) products.
7. **Filtrate reducers.** Filtrate, or fluid loss reducers - such as bentonite clays, CMC (sodium carboxymethylcellulose), and pregelatinized starch - serve to cut filter loss, a measure of the tendency of the liquid phase of the drilling fluid to pass into the formation.
8. **Flocculants.** These are sometimes used to raise gel strength. Salt (or brine), hydrated lime, gypsum and sodium tetraphosphates may be used to cause colloidal particles in suspension to group into bunches, or "flocs", causing solids to settle out.
9. **Foaming agents.** These are most often chemicals that also act as surfactants (surface active agents) to foam in the presence of water. These foamers permit air or gas drilling through water-bearing formations.
10. **Lost circulation materials.** The primary function of a lost circulation additive is to plug the zone of loss back in the formation away from the face of the borehole so that subsequent operations will not result in a loss of drilling fluids.
11. **Lubricants**. Extreme pressure lubricants are designed to reduce torque and increase horsepower at the bit by reducing the coefficient of friction. Certain oils, graphite powder and soaps are used for this purpose.
12. **Pipe-freeing agents.** Consisting of detergents, soaps, oils, surfactants and other chemicals, these agents are intended to be spotted in an area of suspected pipe stickage to reduce friction, increase lubricity and inhibit

formation swelling.

13. **Shale control inhibitors**. Gypsum, sodium silicate and calcium lignosulfonates, as well as lime and salt, are used to control caving by swelling or hydrous disintegration of shales.
14. **Surface active agents.** Surfactants, as they are called, reduce the interfacial tension between contacting surfaces (water/oil, water/solid, water/air, etc.). These may sometimes be emulsifiers, de-emulsifiers, flocculants or deflocculants, depending on the surfaces involved. Some of these additives may pose problems for disposal to the environment.

2.3 COMPONENTS OF DRILLING WASTES

Drilling wastes are comprised of the following:

1. Drilling mud or fluid.
2. Drilled cuttings (geologic material, salts, other).
3. Formation fluids (brines, crude oil).
4. Make-up water.
5. Completion chemicals (acids).
6. Other
    a) rig washes
    b) waste lubricants
    c) coolants
    d) domestic wastes.

The completion chemicals and other rig and camp wastes are normally segregated from the muds and cuttings making overall disposal of the wastes more effective.

3. GUIDELINES/REGULATIONS RELATIVE TO DRILLING WASTE DISPOSAL

The oil and gas industry in Alberta operates under a number of provincial statutes and regulations most of which are listed below.

1.	Energy Resources Conservation Act and Regulations	ERCB
2.	Gas Resources Preservation Act	ERCB
3.	Oil and Gas Conservation Act and Regulations	ERCB
4.	Alberta Environmental Protection and Enhancement Act	A. Env. Prot.
5.	Mines and Minerals Act and Regulations	A. Env. Prot.
6.	Public Lands Act and Regulations	A. Env. Prot. and A. Agriculture, Food and Rural Development

3.1 REGULATORY RESPONSIBILITIES

The management and disposal of drilling wastes is regulated by a number of government agencies. On a province-wide basis the ERCB deals with drilling wastes on private lands and Alberta Environmental Protection and Alberta Agriculture, Food and Rural Development deals with the public lands. Alberta Land and Forest Services (Alberta Environmental Protection) is responsible for crown lands in the Green Area and the Public Land Management Branch (Alberta Agriculture, Food and Rural Development) is responsible for the remaining crown land in the province (Figure 2).

Effective September 1, 1975 the Energy Resources Conservation Board required that all operators comply with the requirements outlined in "Attachment I to Interim Directive No. ID-OG 75-2, Sump Fluid Disposal Requirements" (ERCB 1975). All subsurface disposal of drilling fluids is regulated by the Energy Resources Conservation Board Directive ID-81-1, "Subsurface Disposal of Drilling Fluids" (ERCB 1981).

In 1993 the guidelines contained in ID-OG-75-2 were updated by the joint/government/industry Drilling Waste Review Committee (DWRC) that was formed in 1987. These guidelines (ERCB 1993) are described in pertinent sections of this document.

The operator must apply to the ERCB to drill a well on public and private lands. For public lands the operator must also apply to Alberta Environmental Protection for a licence of occupation (LOC) for the access road, and/or a Mineral Surface Lease (MSL) for the wellsite.

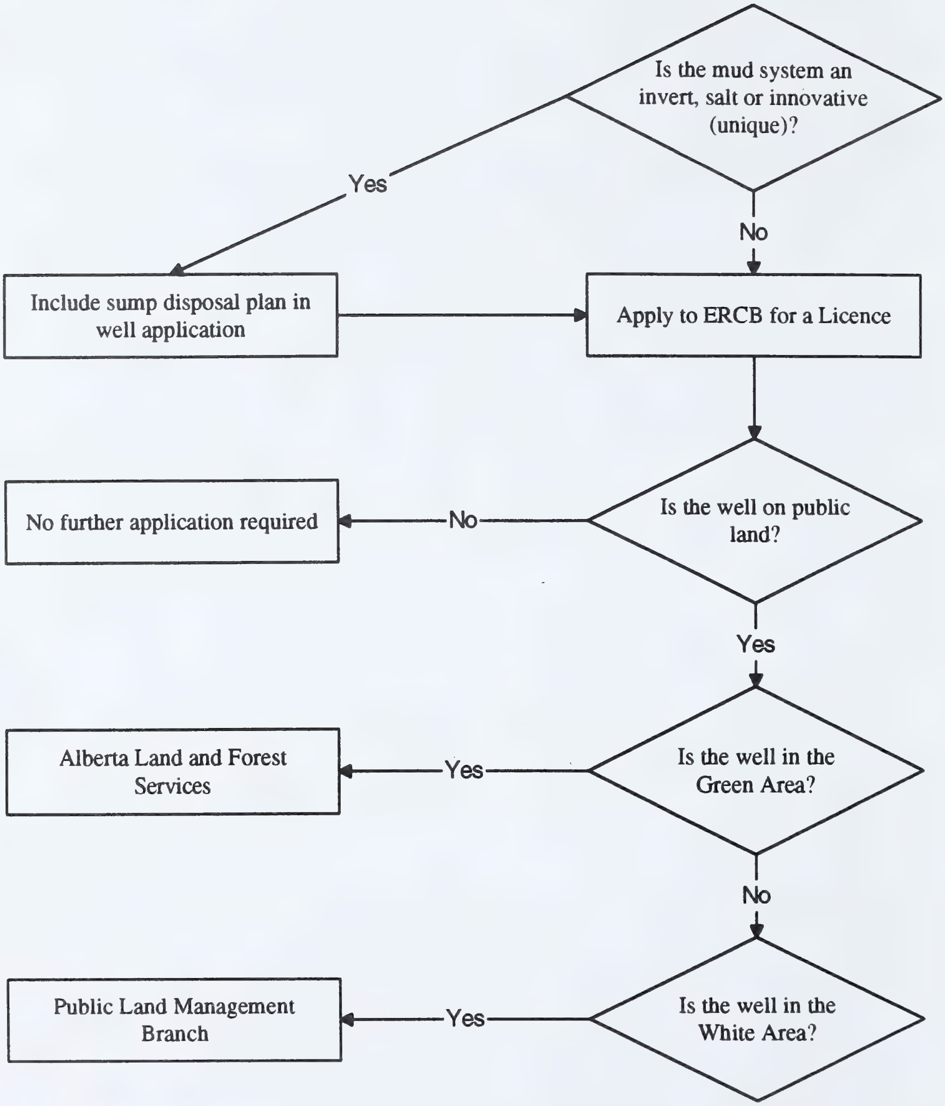
Is the mud system an invert, salt or innovative (unique)?
Yes
No
Include sump disposal plan in well application
Apply to ERCB for a Licence
No further application required
No
Is the well on public land?
Yes
Alberta Land and Forest Services
Yes
Is the well in the Green Area?
No
Public Land Management Branch
Yes
Is the well in the White Area?

Figure 2. Regulatory responsibilities for wellsite licencing.

4. SUMP SITING

4.1 WELLSITE LOCATION

A wellsite is selected on the basis of a number of factors including subsurface geological and geophysical information, provincial oil and gas well spacing and target area regulations and the topographic characteristics of the landscape. The first step in the process is delineation of the target area and specific location for drilling. This is based on detailed seismic surveys and/or subsurface geological mapping which indicate potential hydrocarbon reserves (PITS 1992). The specific location is normally the best location to drill and, depending on the type of reservoir to be drilled, the risk of a Dry Hole or marginal well will increase by moving the location (PITS 1992).

A decision to move the surface location or directionally drill the well from an alternative surface location could be taken for any one of the following reasons (PITS 1992):

1. to conform to the ERCB spacing regulations;
2. to reduce resident or land owner impact;
3. to avoid topography related problems; and,
4. to reduce environmental impact.

A minimum lease size has been established to satisfy the equipment spacing requirement of the ERCB and provide a safe working area (PITS 1992). The minimum lease size is 100 m by 80 m for shallow drilling projects. Larger rigs (4500 and 6000 m capacity) require leases 150 m by 120 m to allow room for rigging up and storage for materials. The lease sizes described are for working space only which includes drilling, production and servicing of the well. Outside the working or useable area there must be allowance for backslope (2:1), sideslope (3:1), drainage diversion, location berm, soil storage, and brush or snowpiles (R. Clark, Petro-Canada Ltd, personal communication). Furthermore, deeper holes require significantly greater amounts of supplies including mud, water, cement, and casing, thereby requiring good all weather roads to the site. The position of the rig on site is determined by access, cut/fill areas and desired sump location (R. Clark, Petro-Canada Ltd, personal communication). The lease is laid out horizontal to the slope with the sump placed in the cut side.

It is obvious therefore that the wellsite location is initially targeted on the basis of geological and geophysical information supporting the potential presence of exploitable resource and provincial well spacing requirements. At this point the location delineated is evaluated from the perspective of environmental suitability (acceptability). There are several questions that come to mind at this point.

1. What makes a site environmentally suitable for sump location?
2 How does one determine if the site is suitable?
3. What characteristics of the site can be assessed or evaluated prior to actually being on site?
4. What parameters can be evaluated on site?
5. What procedures are followed to conduct a site evaluation?

4.2 SUMP LOCATION EVALUATION

The best site for a sump is a well-drained location on level terrain, with fine textured soils and underlying sediments, a deep water table, and an acceptable distance from wells and surface water. The rationale for these conditions is that a well drained site is not likely to be flooded and contaminate surface water (however, too well drained could indicate rapid percolation of soluble sump compounds and possible groundwater contamination). Sites on level terrain are less prone to erosion which can result in contaminated water flowing offsite and the fine textured soils and sediments have slow percolation rates which reduces the possibility of groundwater contamination. A deep water table is less likely to be affected than a shallow one, and having no nearby wells or surface water will limit problems if groundwater does become contaminated or if surface water flows offsite.

Many of the conditions that determine site suitability for a sump can be assessed visually at the site (for example, slope angle or proximity of surface water), or can be obtained from reference maps and documents (for example, soil type, topography, and surficial geology). Considerable information can also be obtained through an understanding of the relationships between soils, vegetation, topography, drainage, and surficial geology, and using these relationships to interpret the landscape. This latter information is particularly useful for site specific information, as many maps do not show variations within an area the size of a wellsite. These information sources complement other aspects of field inspection and sampling.

There are three major steps involved in evaluating a lease for sump location: (1) office-information gathering; (2) field inspection; and, (3) environmental evaluation. Each of these steps are discussed in detail below. A flow chart of the process involved is given in Figure 3.

4.2.1 Office - Information Gathering

This step involves the review of existing relevant information pertinent to the lease site. The review can result in a basic understanding of the lease environment, with an awareness of potential environmental problems, and identification of knowledge or data gaps. In collecting the existing information about a lease site, particular attention should be paid to information pertaining to the topography, soil, surficial geology, vegetation, land use, surface water hydrology and hydrogeology of the site. Sources of existing information are discussed below and summarized in Table 1. A good general reference for sources of information is found in Appendix B of the Canadian Petroleum Association's Environmental Operating Guidelines for the Alberta Petroleum Industry (1988).

Following acquisition of existing information the following steps should be undertaken:

1. Review information for level of detail. The required level of detail for each category (topography, soil, surficial geology, vegetation, land use, surface water hydrology, and hydrogeology) of information collected is provided in the appropriate section below.

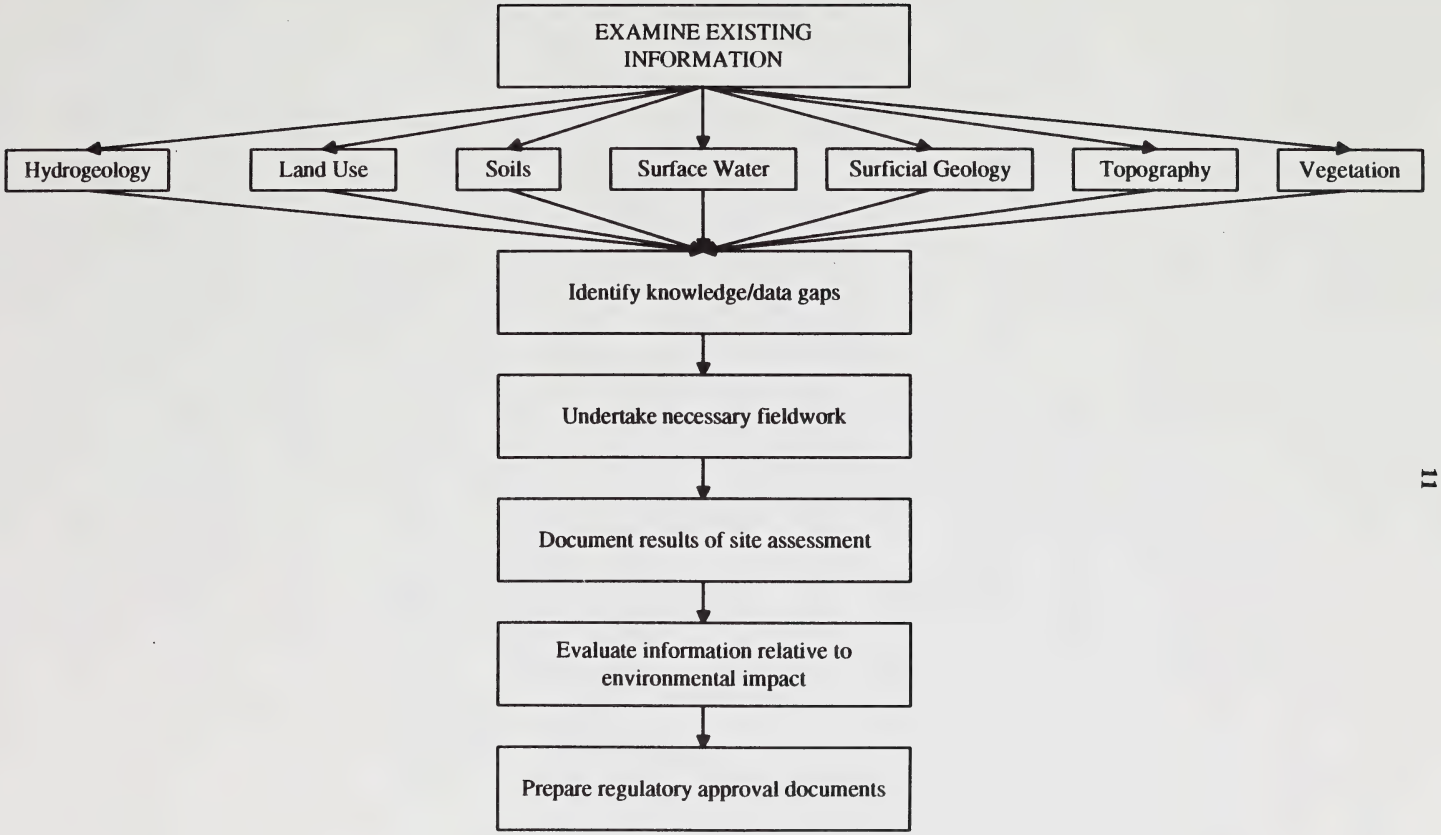
EXAMINE EXISTING INFORMATION
Hydrogeology
Land Use
Soils
Surface Water
Surficial Geology
Topography
Vegetation
Identify knowledge/data gaps
Undertake necessary fieldwork
Document results of site assessment
Evaluate information relative to environmental impact
Prepare regulatory approval documents

Figure 3. Steps involved in evaluating a lease for sump location.

Table 1. Information sources. (Details for contacting the various agencies are given in Appendix 1).

Information Type	Sources	Available From
General	• Environmental Operating Guidelines for the Alberta Petroleum Industry	Canadian Association of Petroleum Producers
	• Natural Resources Information Directory	Information Centre, Alberta Environmental Protection (AEP)
	• Alberta Research Council Publications List	Alberta Research Council
	• ERCB Publications, Maps and Services Catalogue	ERCB
Groundwater-Hydrogeology	• Groundwater Resources Information Services	Alberta Environmental Protection
	• Existing hydrogeology maps	Alberta Research Council
	• Bedrock topography maps	Maps Alberta (AEP)
	• Borehole, testhole data	Company files
Land Use	• Air photos	Maps Alberta (AEP)
	• Canada Land Inventory and Alberta Land Inventory maps	Maps Alberta (AEP)
	• Biophysical Analysis and Evaluation of Capability reports	Resource Evaluation and Planning, (AEP)
Soils	• Air photos	Maps Alberta (AEP)
	• Alberta Soil Survey maps and reports	Index of Soil Surveys (Alberta), Agriculture Canada
	• Canada Land Inventory Maps, Soil Capability for Agriculture series	Maps Alberta (AEP)
Surface Water	• Air photos	Maps Alberta (AEP)
	• Site specific reports and studies	Technical Services Division, (AEP)
	• Topographic maps	Maps Alberta (AEP)

continued ...

Table 1. Concluded.

Information Type	Sources	Available From
Surficial Geology	• Air photos	Maps Alberta (AEP)
	• Existing surficial geology maps and reports	Maps Alberta (AEP) Alberta Research Council, Geological Survey of Canada
	• Bedrock topography maps	Maps Alberta (AEP)
	• Soil survey maps and reports	Index of Soil Surveys (Alberta), Agriculture Canada
	• Physical Land Classification maps	Maps Alberta (AEP)
	• Groundwater Resources Information Services	Alberta Environmental Protection
Topography	• Stereo air photos	Maps Alberta (AEP)
	• Topographic maps	Maps Alberta (AEP)
	• Site survey data	Company files
Vegetation	• Air photos	Maps Alberta (AEP)
	• Canada Land Inventory maps	Maps Alberta (AEP)
	• Ecological Land Classification and Evaluation reports	Resource Evaluation and Planning Division (AEP)
	• Alberta Forest Service Base Map - Provincial Record (Forest Cover Maps)	Maps Alberta (AEP)
	• Forest Cover maps	Maps Alberta (AEP)
	• Land Capability for Forestry	Maps Alberta (AEP)

2. If it appears adequate, provide summary of information to level or degree required for approval by regulatory agency.

If it is not adequate, undertake the necessary work to improve the quality of information available. The work necessary is described in the Field Inspection section.

4.2.1.1 Hydrogeology. The factors that control whether or not groundwater contamination will occur at a given site are:

1. the physical and hydraulic characteristics of the subsurface material, as represented by D'arcy's Law (hydraulic gradient, hydraulic conductivity, porosity); and,
2. the nature and concentration of the contaminant (i.e., in particular the soluble, and therefore mobile, components of the mud system used that have undesirable environmental effects).

The first factor determines the potential for the contaminant to reach a possible aquifer whereas the second factor evaluates the risk associated with the contaminant entering the aquifer.

In light of these factors, knowledge of the hydrogeologic conditions at the lease site is required to evaluate the groundwater contamination potential of the site. Data pertaining to the lease site's hydrogeology can be found, to some degree, in the sources listed in Table 1. If boreholes or testholes with hydrogeologic data in close proximity of the site are not available, or the terrain is particularly complex, additional site specific data will be required. Details pertaining to field investigation requirements are included in the Field Inspection section.

4.2.1.2 Land Use. Land use information provides an indication of ultimate reclamation requirements for the site, which implies procedures that should be followed during the course of operations at the site. Sources of this information are listed in Table 1. It is unlikely that further field work will be required for this category.

4.2.1.3 Soils. The physical and chemical characteristics of the soil(s) at a given location have a bearing on whether or not the site is suitable for locating a sump. General information about soils at the lease site can be obtained by examining air photos and existing soil surveys.

Map scales more general than 1:10,000 would necessitate more detailed site investigation for an area the size of a well lease location, but would provide some useful general information. Refer to the Field Inspection section for more details pertaining to an on-site soil survey.

The Index of Soil Surveys in Alberta (1990), available from Agriculture Canada, lists the soil surveys available, where they may be obtained and who to contact for further information. Soil survey maps and reports will provide information on topography, physical and chemical properties of the soil and in particular, information about the texture of the materials and drainage characteristics. The soil map also provides information pertaining to the parent material, which in turn gives an indication of the surficial geology.

The document entitled "Soil Series Information for Reclamation Planning" (L. Knapik, in prep.) provides useful information regarding the characteristics of the major soils occurring in Alberta.

4.2.1.4 Surface Water. A sump cannot be constructed within 100 metres of the normal high water mark of a surface water body. A surface water body includes any body of water (slough, dugout, lake), permanent stream or potable water well. The position of the lease with respect to surface water in the area can be determined from air photos, and/or topographic maps. If the scale of the topographic map is too general, then additional information must be obtained through a field survey. This could be done as part of the topographic site survey.

4.2.1.5 Surficial Geology. The type of surficial material present and its thickness is important in determining the suitability of a site for locating a sump. Pauls et al. (1988) state "In general terms, all surficial sand, gravel and coarse-grained, well-sorted silt deposits should be avoided in selecting a location for a sump. The silty and clayey deposits of lakes may, in some places, afford adequate confinement for location of sumps."

To determine the surficial geology of the lease site, the sources listed in Table 1 can be used. Use of the surficial geology map will yield information pertaining to the type and thickness of the material present, and local topographic relief. Boreholes from the Groundwater Resources Information Services (GRIS) data files, in close proximity of the lease site can be used to substantiate information acquired from maps. If reliable borehole data near the lease area are not available a field investigation will be required to determine the surficial material present. Details of such an investigation are provided in the Field Inspection section.

Table 2 describes the major parent materials occurring in Alberta and the relationship of their respective characteristics to sump siting and drilling waste disposal.

4.2.1.6 Topography. A sump should be located on the high side of the lease. In addition, rain or snow runoff diversion ditches around the lease should be installed if required. Topographic maps provide a range of information that includes landscape relief (both local and regional), locations of surface water bodies, surface drainage, and inferences of the water table position. Potential sources of topographic information are given in Table 1. If it is not possible to determine the topographic configuration of the site from available sources, a site survey will be required.

4.2.1.7 Vegetation. Vegetation information provides some indication of current land use and general requirements for ultimate reclamation of the site. Vegetation information in the absence of any other information provides some clues with regard to soil type (characteristics), drainage, surficial geology, and topography. Sources of this information are listed in Table 1. If vegetation information is unavailable, or is at too broad a scale, a field inspection will be required, details are provided in the Field Inspection section.

Table 2. Parent Material Characteristics and Their Relationship to Sump Siting and Drilling Waste Disposal.

Parent Material	Associated Landform/Topography	Dominant Textures	Important Features
Eolian	• dunes • gently undulating plains	• sands • loamy sands no stones • well sorted	• very low water holding capacity • rapid permeability • high potential for deep percolation • very low fertility • difficult to revegetate
Fluvial	• floodplains • terraces • undulating plains • often dissected	• sands • silts • gravels, cobbles rarely clays • generally well sorted • stratified occasionally massive • non-sorted	• flooding on floodplains • low water holding capacity • permeability varies with stratification • high potential for lateral flow • groundwater often shallow on recent floodplains • sands/gravels have low fertility and are difficult to revegetate
Lacustrine and Lacustro-till	• level to undulating plains • rarely hills	• silty clays • silty clay loams • clays • clay loams few to no stones • well to moderately sorted • stratified	• high to very high water holding capacity • low potential for deep percolation • often overlies slightly more permeable materials (till) • depressions often contain wetlands • water ponding after rains or snowmelt • difficult to work if too wet or too dry
Fluvial-Lacustrine	• undulating plains • rarely hills	• silts • sandy loams • loams	• moderate water holding capacity • permeability varies with texture and stratification • moderate potential for lateral flow and deep percolation • depressions often contain wetlands

continued ...

Table 2. Continued.

Parent Material	Associated Landform/Topography	Dominant Textures	Important Features
Till (Plains)	• undulating plains • hills • hummocky terrain	• loams, clay loams clays • few stones to very stony • non-stratified	• moderate to high water holding capacity • moderate to slow permeability • some potential for lateral percolation through cracks and sandy lenses • generally low potential for deep percolation • wetlands abundant in hilly and hummocky areas
Till (Foothills/ Mountains)	• strongly rolling • ridges • steeply sloping	• sandy loams, silt loams and loams • few to many coarse fragments • non-stratified	• low to moderate water holding capacity • rapid to moderate permeability depending on coarse fragment content • high potential for lateral and deep percolation through cracks and sandy lenses • wetlands restricted to valleys between ridges • low fertility • difficult to revegetate
Weathered Bedrock (plains)	• undulating plains • hilly • low potential for deep	• silts and clays • rarely sands • no stones	• high water holding capacity • slow to very slow permeability often stratified percolation but may have lateral percolation through coarser strata • water ponding after rains or snowmelt • high salinity/sodicity in marine bedrocks • low fertility • difficult to revegetate

continued ...

Table 2. Concluded.

Parent Material	Associated Landform/Topography	Dominant Textures	Important Features
Weathered Bedrock (Foothills/ Mountains)	• strongly rolling • ridges • steeply sloping	• sands and silts • many bedrock fragments often stratified	• low to moderate water holding capacity • rapid to moderate permeability depending on coarse fragment content and texture • high potential for lateral and deep percolation through cracks • low fertility • difficult to revegetate
Organic	• depressional peatlands	• peat	• very high water holding capacity • high water table resulting in anaerobic conditions • highly susceptible to groundwater contamination • difficult to traverse with machinery

4.2.2 Field Inspection

4.2.2.1 Hydrogeology. If the lease site requires an investigation to determine the hydrogeologic parameters necessary to properly evaluate the site, the following references are recommended to assist in planning the investigation. The references cited cover the installation, testing, and monitoring of water table wells and piezometers.

1. Bouwer, H. and R.C. Rice, 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research 12 (3): 423-428.
2. Hvorslev, M.J, 1951. Time lag and soil permeability in groundwater observations. U.S. Army Corps of Engineers, Waterways Experimental Station. Bulletin 36. Vicksburg, Mississippi.
3. Jean, G., G. Sjostrom, G. Sterenberg and R. Stein, 1988. Drilling and installation of instrumentation. IN: Proceedings of Dryland Salinity Control Workshop. Alberta Agriculture, Conservation and Development Branch. pp. 147-159.
4. Johnson Division UOP Inc, 1966. Groundwater and wells. Edward E. Johnson Inc., St. Paul, Minnesota.
5. Morrison, R.D, 1983. Groundwater monitoring technology. Procedures, equipment and applications. Timco Mfg. Inc., Prairie du Sac, Wisconsin.
6. U.S. Department of the Interior, 1981. Groundwater Manual, A Water Resources Technical Publication. U.S.Department of the Interior, Water and Power Resources Service.

4.2.2.2 Soils. Site investigations should follow the guidelines for conducting a soil survey as given in either of the following publications:

1. Agriculture Canada Expert Committee on Soil Survey, 1987. The Canadian System of Soil Classification, Second Edition. Agriculture Canada Publication 1646.
2. Alberta Soils Advisory Committee, 1987. Soil Quality Criteria for Disturbance and Reclamation (Revised). Soils Branch, Alberta Agriculture.

4.2.2.3 Surficial Geology. A surficial geology investigation has no established guidelines such as the ones cited for soil surveys. However, the following general guidelines can be stated:

1. The near surface sediments can be examined in much the same way as for a soil survey. In fact, the soil survey maps provide reliable information about the surficial geology to a depth of one metre. For locating a sump on a lease site, however, a deeper investigation will be required to define the subsurface distribution, thickness and properties of the geologic materials.

2. A surficial geology investigation can be done by a variety of methods such as borehole logs, backhoe excavation or outcrop examination. The method used would depend on its suitability to the terrain in question, as well as its economic viability.
3. The borehole spacing or examination will depend on the terrain of the lease location, the expected continuity of surficial units, and the presence of glacially deformed and/or displaced sediment.
4. The depth of boreholes or backhoe excavation will depend on the material present, the presence of shallow aquifers, and the depth of excavation required for sump construction. In general, however, the investigation should examine the material to a depth of at least 5 metres.

4.2.2.4 Vegetation and Land Use. A site investigation regarding vegetation involves a description of the major tree, shrub, herb and grass species present at the lease location. Land use is described in terms of current use, i.e., agricultural crop, grazing, commercial forest, wildlife habitat. Presence of nearby buildings and the zoning of the lease should also be noted.

4.2.3 Interpretation of Landscape Features

The data collected from the office information gathering and field inspection stages must be interpreted with regard to suitability for sump location in light of environmental considerations. Much of this information can also be used as a check on other data; for example, vegetation type is an indication of sediments and drainage conditions.

4.2.3.1 Topography. Topography is an important factor in the choice of sump location. Steep slopes are poor locations because of the risk of contaminants flowing offsite, depressions are poor choices because they have a relatively high water table and may be prone to flooding. Gently sloping upland areas are the best locations because they are usually well drained, have a deep water table, and are not subject to flooding.

Topography can indicate a great deal about the underlying sediments. Expansive level terrain may indicate fine textured lacustrine materials with slow drainage which are good conditions for a sump. Hilly or rolling terrain generally indicates well mixed tills that may have a considerable content of rock fragments; this is not a good sump location if coarse fragments exceed about thirty percent as percolation may be too rapid. Hilly terrain with no evidence of water accumulation in the depressions may indicate extensive coarse textured sediments with rapid drainage, marginal conditions for siting a sump. Table 3 provides suitability rankings pertinent to slope, distance to surface water and flooding in terms of evaluating the suitability of a lease site for construction of a sump. The most limiting property for each parameter determines the ultimate rating for a site.

Topography maps, soils maps, surficial geology maps, and stereo air photos provide information on the general topography and underlying sediments in an area. More detailed information on site specific topography must be collected by onsite inspection.

4.2.3.2 Soils and Surficial Deposits. Because soil development usually extends to only about one metre in depth, soils are not as important as the underlying sediments for containment of sump contents. The type of soils present at a site also provide an indication of the vegetation, climate, drainage, and surficial geology of the location. Soils are important for site reclamation and disposal of sump contents by landspreading or landfarming.

Texture is the most important soil property for sump placement because texture has a substantial effect on drainage and the potential for groundwater or surface water contamination. Coarse textured soils and surficial deposits have too rapid percolation and may allow groundwater contamination; fine textured materials are much better, provided that percolation is not so slow that drainage is impeded and runoff becomes a problem. Because sumps are generally at least two to four metres deep, the texture of surficial deposits is more important than the texture of the soil. Information on surficial deposits is available from surficial geology maps; however, this information is usually not at a scale that shows onsite differences -- site inspection provides more detailed information.

Gleysolic soils which indicate wet soil conditions with a shallow water table represent very poor locations for sumps and should be avoided.

Soil survey maps indicate specific soil types for an area, as well as providing a substantial amount of additional information regarding the landscape. The maps present the information at a variety of scales and with different nomenclature. This variability is a function of mapping history -- mapping techniques/ tools, and evolution of classification systems and cartographic techniques.

Most maps use map unit symbols that indicate the soil series or association as well as the topography of the specific unit. The topographic component is generally indicated by a letter (a, b, c, etc.) or a number (1, 2, 3, etc.). The soil unit description can be used to infer features regarding surficial geology and drainage for the specific area. More specifically, the drainage characteristics of the area can be identified, as well as whether lacustrine, till, aeolian, bedrock, or other materials are present. Furthermore, the maps provide information regarding soil texture and certain chemical properties (for example, soils mapped as Solonetzic could have high EC and/or SAR values).

Table 3. Suitability of landscape features for sump location (After Leskiw et al. 1987).

	Suitability			
Parameter	High	Moderate	Marginal	Unsuitable
Slope[1]	0 - 9%	>9 - 15%	>15 - 30%	>30%
Distance to surface water	>300 m	100-300 m	<100 m	<100 m
Flooding	No occurrences	No occurrences	Rare occurrences (1 in 10 years)	Occasional to frequent occurrences

[1] It is assumed that the lease area, in particular the portion of the lease where the sump(s) will be located, will be levelled.

Table 4 provides suitability rankings pertinent to texture, permeability, drainage and coarse fragment content in terms of evaluating the suitability of soils and surficial materials at a given location for sump construction. Again, the most limiting parameter determines the rating for a site.

4.2.3.3 Vegetation. Different vegetation species are adapted to specific site conditions, so an examination of natural vegetation patterns is an indicator of climate, soils, surficial geology, drainage and salinity. On the broadest of scales, forests develop under relatively moist site conditions, grasslands develop under dry conditions, and aspen parkland (a mixture of groves of aspen and patches of grassland) develop under intermediate moisture conditions.

This can be an important consideration for disposal of sump wastes because under moist forest conditions the soluble compounds such as salts will be leached downward (with possible groundwater implications), while in dry grassland areas these salts may persist near the soil surface (with implications for salinization).

Within these broad zones the specific species growing at a site can yield additional information. On forested sites, jack pine (Pinus banksiana) thrives in dry, sandy, well-drained sites that may pose problems for sump siting, and reclamation may be difficult because of the droughtiness of the soil.

Table 4. Suitability of soils and surficial materials for sump location.

	Suitability			
Parameter	High	Moderate	Marginal	Unsuitable
Texture[1]	C, HC, SiC, SC	L, CL, SiCL, Si, SiL	SL, LFS	LS, S, gravel, peat, muck
Permeability	Moderately slow to very slow < 15 mm/hr	Moderate 15-50 mm/hr	Moderately rapid >50-150 mm/hr	Rapid to very rapid >150 mm/hr
Drainage	Well to moderately well	Imperfectly	Rapidly (if no groundwater contamination), poorly	Very poorly, very rapidly
Coarse fragment content (by volume)	<10%	10-30%	>30-50%	>50%

[1] See Glossary - Soil Texture for symbol definitions.

Aspen (Populus tremuloides) favors dry to moist sites with fine to medium textured soils; balsam poplar (Populus balsamifera) becomes dominant on moister sites. Aspen poplar may indicate good potential sump sites. White spruce (Picea glauca) is dominant on moist sites with fine textured soils; these are also potentially good sump locations. Balsam fir (Abies balsamea) is never dominant, but is scattered through the forests in eastern Alberta on moist to wet sites, and may indicate a shallow water table. Tamarack (Larix laricina) grows on very wet sites with shallow water tables and poor drainage, definitely poor locations for a sump. In the southern portion of Alberta's forested zone, black spruce (Picea mariana) also grows on very wet sites; in the northeast of the province it grows at the other extreme, on dry sandy soils where competition from other species is limited. Neither of these locations are well-suited for sumps because the water table is too shallow on the wet sites, and percolation may be too rapid on the sandy sites.

It is important to note that these dominant vegetation patterns are for natural vegetation distribution; recent disturbances can confuse the interpretation. For example, black spruce is capable of growing on sites ranging from extremely wet bogs to dry, sandy soils. However, it is a poor competitor with other trees because of its slow growth and relatively small stature so, on most sites, it cannot compete with taller and faster growing white spruce, aspen, poplar, or pine. This restricts black spruce to sites where these other species do not grow well -- very wet sites throughout the forest, dry sites in the extreme northeast where cold temperatures hinder jack pine, and in a mixture with white spruce on moist sites in the north of the province where cold temperatures make white spruce a less vigorous competitor. Human disturbance such as logging can sometimes invalidate these assumptions and make site interpretation more difficult.

In the aspen parkland zone of Alberta, as sites become moister the aspen mixes with balsam poplar and occasionally white spruce in the northern portion of the zone, or cottonwoods (Populus angustifolia and Populus trichocarpa) in the southern portion of the zone. Willows (Salix spp.) characterize the wettest sites, which are unsuitable locations for sumps.

Grasses in the grassland and aspen parkland zone are more difficult to interpret because most of the area has been disturbed by cultivation and grazing. Moist sites generally have the tallest grasses, while dry sites are characterized by the shortest grasses. In areas of native vegetation these different grass heights are associated with a change in grass species, while in areas seeded to a single grass species the height difference is generally related to moisture supply (for example, native western wheatgrass (Agropyron smithii) grows to 30 cm on dry sites and 90 cm on wetter sites. Sagebrush (Artemisia) and prickly pear cactus (Opuntia) grow on very dry sites. Dry sites may be good locations for sumps provided that the dryness is not a result of highly porous sediments. Sedges (Carex spp.) characterize wet sites. Alkaligrass (Distichlis stricta) and foxtail barley (Hordeum jubatum) grow on saline sites (salinity is usually an indicator of wet, poorly drained soils, not suitable for sumps), and salt meadow grass (Puccinellia nuttalliana) is common on moist alkaline ground.

The native prairie in Alberta is defined as "an area of unbroken grassland or parkland dominated by non-introduced species" (ERCB 1992). These areas are particularly sensitive in that re-establishment of the native vegetation is difficult and introduction of non-native species can result in inferior grazing and altered habitat while also affecting the re-establishment of native species on the disturbed site (ERCB 1992). As a result, sump should not be excavated in native prairie; tanks or other alternatives should be considered.

Information on vegetation is available from vegetation maps, forest cover maps, ecological classification maps, aerial photographs, and site interpretation.

4.2.3.4 Hydrogeology. Important features related to groundwater and sump siting include depth and thickness of the permeable unit, flow direction, proximity of existing or potential water supply sources, waste type and depth to water table. Table 5 provides an evaluation of the potential for groundwater contamination based on these features.

Table 5. Evaluation of Potential for Groundwater Contamination. Factors are Listed in Order of Importance.

	Potential for Contamination		
Factors	Low	Medium	High
Vertical hydraulic gradient (direction)	upward (discharge)	downward (recharge)	downward (recharge)
Proximity of receiving body or users			
- distance (m)	> 500	200 - 500	< 200
- direction[1]	upgradient	downgradient	downgradient
Waste type - composition[2]	water	gel chemical	invert, KCl, NaCl
Depth to water table	> 6 m	2 - 6 m	< 2 m

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[1] As a conservative estimate, all pumping wells can be considered downgradient of the sump because of the cone of depression that is developed around the well during pumping.

[2] Potential for contamination in general or relative terms.

5. DRILLING WASTE SAMPLING

All liquids and solids produced from the drilling operation must be sampled and analyzed to determine their characteristics. It must be recognized that in characterizing a sump the analytical work and interpretation of results are only as good as the samples obtained, therefore care and caution must be employed during the sampling process. The samples must be representative of the entire sump contents and must be collected in a manner that represents the plan for disposal. For example, for sumps with visible hydrocarbon on the surface the sample collected should include the hydrocarbon material if the intent is to dispose of the sump liquids without first removing the visible hydrocarbon. Conversely, if the intent is to remove the hydrocarbon prior to disposal then the sample should be collected without the hydrocarbon.

This section describes the procedures that should be employed to obtain representative samples for analysis. The outline provided cannot take into consideration all the different site specific conditions that may be encountered by the sampler.

5.1 SITE AND SAMPLING INFORMATION REQUIREMENTS

Background information regarding the contents of the sump sampled and a description of the location and sampling procedures utilized is important in the interpretation of the analytical results and development of disposal options. A sampling site description form (Figure 4) and sample description form (Figure 5) should be completed for each sump location sampled. The site description form should document the following.

1. Name(s) of sampler(s).
2. Date of sampling.
3. Legal location of sump (well) site.
4. Sketch of sump(s) denoting dimensions (length, width, depth) and approximate subsample site locations.
5. Type of containers used.
6. General comments regarding appearance of sump and material sampled i.e. color, "texture", odour if any.
7. Ease or difficulty in obtaining samples - problems encountered.

5.2 SAMPLING METHODS

Methods utilized will vary based on the size and nature of the sump and its contents as well as the time of year of sampling. The components to sample are dependent upon waste type and to some extent on the procedures for ultimately disposing of the material, however both the liquids and solids must be sampled separately. Procedures for sampling drilling wastes and receiving soils are outlined in Figures 6, 7, and 8.

The time of sampling depends upon operational requirements and logistics, and the material to be sampled. A general recommendation is that the sampling event occur preferably no more than 30 days prior to disposal.

Figure 4. Sump Sampling Site Description

Location: ____________________

Company: ____________________ Date: ____________________

Sampled by: ____________________ Sump No: ____________________

Mud Type: ____________________ Sump Vol: ____________________m^3

Total Fluid Vol: ____________________m^3 Total Mud Vol: ____________________ m^3

Sump: Onsite: __________ Remote: __________ Sump Freeboard: ____________________m

Sump Type: ____________________ Sump Area: ____________________m^2

Sump and Site Description/Observations:

Figure 5. Sample Description Form

Sump No. __

Hole Number	Liquid Depth	Solid Depth	Total Depth	Sample Number	Depth	Plastic Bag	Plastic Bottle	Glass	pH	L/S*

* L/S - Liquid or Solid Phase

COMMENTS:

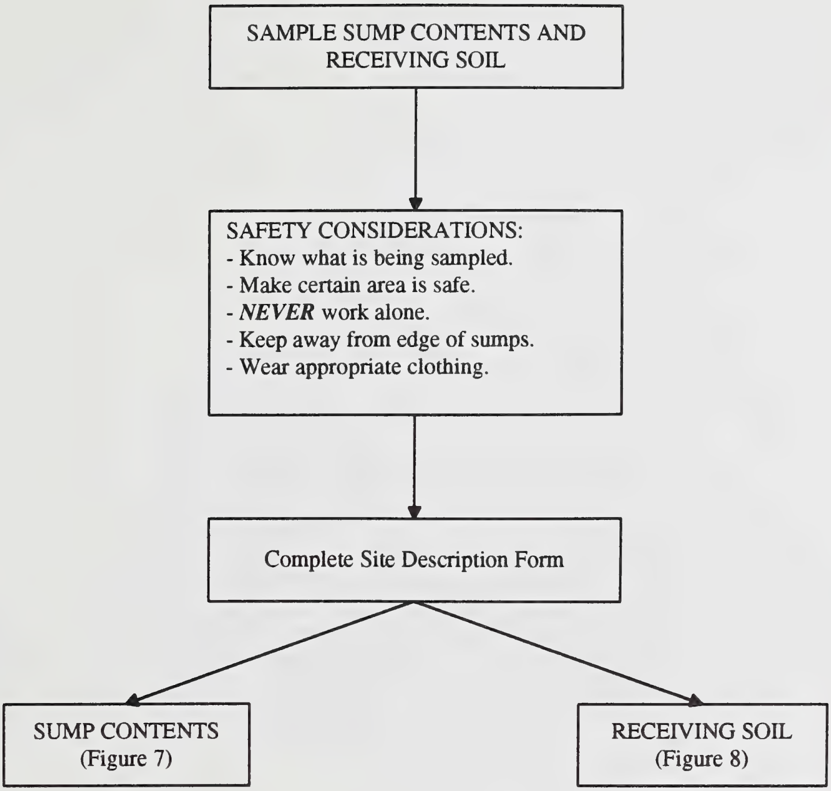
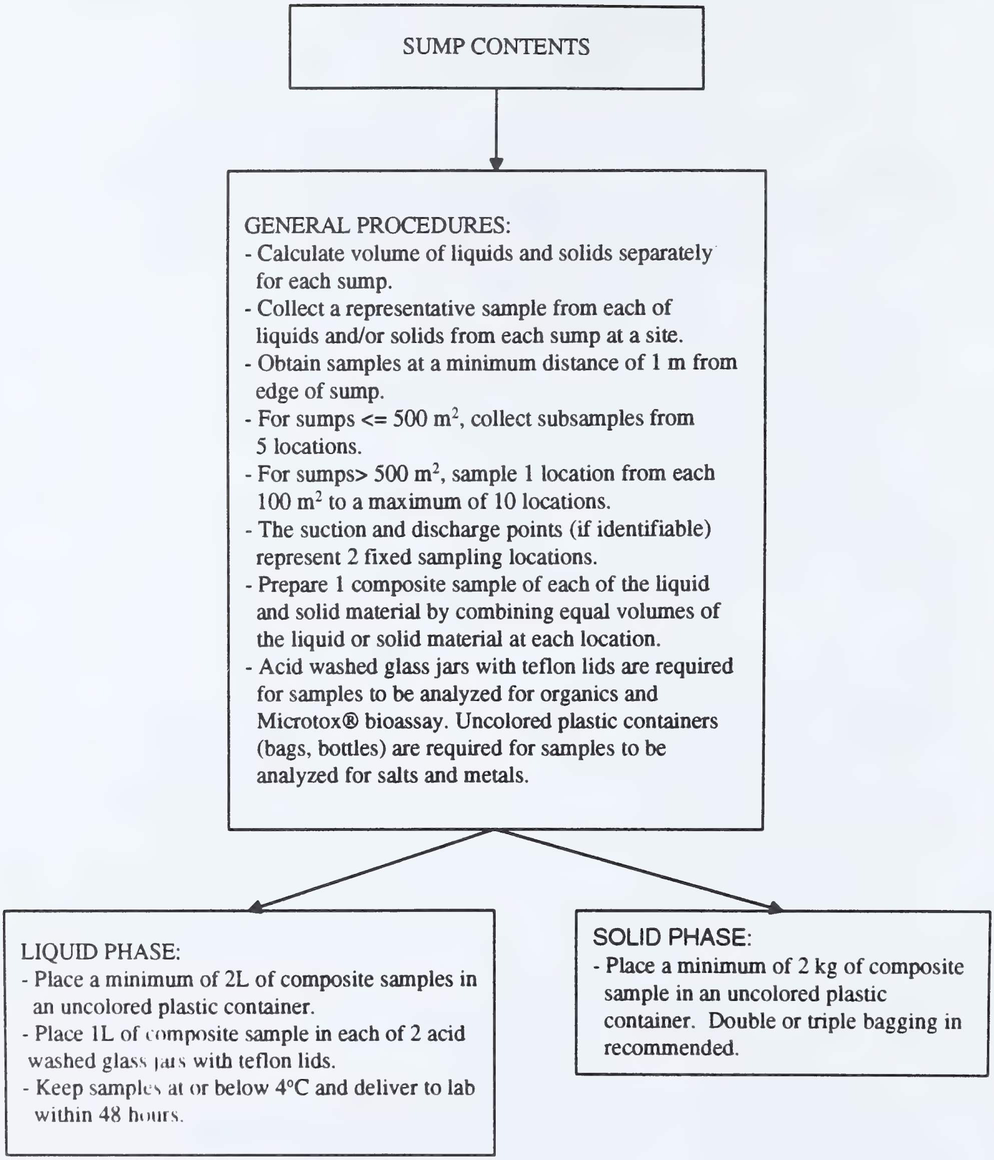

SAMPLE SUMP CONTENTS AND RECEIVING SOIL
SAFETY CONSIDERATIONS:
- Know what is being sampled.
- Make certain area is safe.
- NEVER work alone.
- Keep away from edge of sumps.
- Wear appropriate clothing.
Complete Site Description Form
SUMP CONTENTS (Figure 7)
RECEIVING SOIL (Figure 8)

Figure 6. General procedure for sampling drilling wastes and receiving soil.



GENERAL PROCEDURES:

- Calculate volume of liquids and solids separately for each sump.
- Collect a representative sample from each of liquids and/or solids from each sump at a site.
- Obtain samples at a minimum distance of 1 m from edge of sump.
- For sumps <= 500 m^2, collect subsamples from 5 locations.
- For sumps> 500 m^2, sample 1 location from each 100 m^2 to a maximum of 10 locations.
- The suction and discharge points (if identifiable) represent 2 fixed sampling locations.
- Prepare 1 composite sample of each of the liquid and solid material by combining equal volumes of the liquid or solid material at each location.
- Acid washed glass jars with teflon lids are required for samples to be analyzed for organics and Microtox® bioassay. Uncolored plastic containers (bags, bottles) are required for samples to be analyzed for salts and metals.

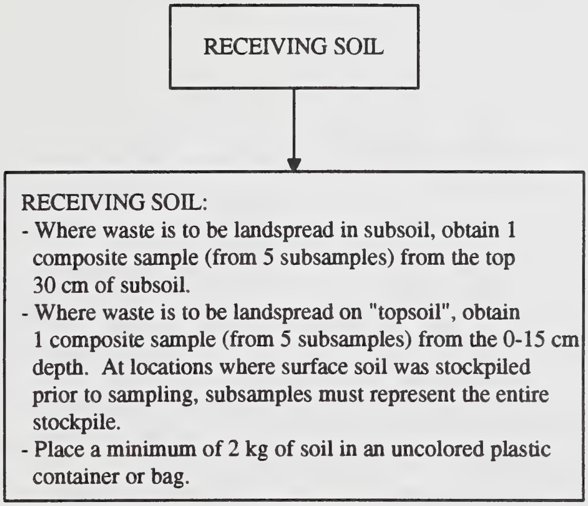
LIQUID PHASE:

- Place a minimum of 2L of composite samples in an uncolored plastic container.
- Place 1L of composite sample in each of 2 acid washed glass jars with teflon lids.
- Keep samples at or below 4°C and deliver to lab within 48 hours.

SOLID PHASE:

- Place a minimum of 2 kg of composite sample in an uncolored plastic container. Double or triple bagging in recommended.

Figure 7. Procedures for sampling liquid and solid phase drilling wastes.



RECEIVING SOIL

RECEIVING SOIL:

- Where waste is to be landspread in subsoil, obtain 1 composite sample (from 5 subsamples) from the top 30 cm of subsoil.
- Where waste is to be landspread on "topsoil", obtain 1 composite sample (from 5 subsamples) from the 0-15 cm depth. At locations where surface soil was stockpiled prior to sampling, subsamples must represent the entire stockpile.
- Place a minimum of 2 kg of soil in an uncolored plastic container or bag.

Figure 8. Procedure for sampling receiving soil.

The season (winter vs. non-winter conditions) during which sampling is undertaken has various advantages and disadvantages. For example, dilution by rainfall and sample deterioration is less of a concern during the winter. On the other hand, ice concentrates chemicals and cold conditions can create problems regarding freezing of samples in glass containers.

A variety of suitable sampling tools is available. The tools should be fabricated from clear plastic, stainless steel, or other materials which minimize the potential for sample contamination.

A number of alternatives including the use of backhoes, cherry pickers and boats are available for sampling sumps that cannot be adequately sampled by hand from the margin. The equipment and/or approach utilized for sampling a sump will be based on site specific conditions and sampler preference, however the ultimate goal of obtaining representative samples must be achieved.

5.3 SAFETY CONSIDERATIONS

Safety is the prime consideration when planning and executing a sump sampling program. The following points address some of the major factors that must be considered.

1. Know what is being sampled and be aware of the associated hazards.
2. Make certain that the area is safe, for example determine H2S levels at sites where it might be of concern.
3. Keep away from the edge of sumps to the extent possible. They may be unstable because of undercutting during construction. Footing is a major consideration under wet or icy conditions, or where liners have been used.
4. Use appropriate clothing - gloves, safety glasses, coveralls (special suits) and proper footwear. Precautions must be taken to keep materials from being ingested or making contact with the eyes. Most of the waste types will cause severe drying of the skin and create discomfort if in contact with open wounds, etc.
5. NEVER work alone. It is recommended that three people be present/involved during sump sampling, particularly when a boat or other vessel is being used. The usual precautions that are associated with the use of a boat or similar vessel must be followed. All individuals must be wearing personal flotation devices and the vessel must be secured to the sump edge. There must be two individuals in the vessel to expedite the sample collection and one person "on shore" or at the sump edge at all times.

5.4 GENERAL PROCEDURES

This section describes the general procedures that should be employed to obtain representative samples for analysis under the requirements of ID-93-1 for drilling waste in Alberta. More detailed sampling of selected sumps to determine variability within a given sump was completed and described by Macyk et al. (1989). This detailed sampling and characterization work formed the basis for the sampling protocols outlined herein. The material provided below outlines the procedure for determining the volume of the waste(s) and the protocols for collecting the appropriate samples. Details regarding liquids, solids and receiving soil sampling are described subsequent to this.

The procedure is relatively straightforward for single sump sites and single mud systems and for situations where multiple mud systems and multi-celled sumps have been utilized.

1. Determine the nature of the contents of the sump or in the case of multiple sumps each discrete unit. For example, at some locations different mud systems such as freshwater gel and invert or freshwater gel and KCl or other combinations may be utilized. In these situations the waste systems would be kept in separate sumps. In some situations there may be one sump containing liquid phase materials that have been drained or decanted from an adjacent sump containing the solids portion. This information should be available from drilling records and provided to the sampler(s).
2. Calculate the volume of liquids based on the average depth and area. Calculate the volume separately for each cell at a given site.
3. Calculate the volume of solids based on the average depth and area. Calculate the volume separately for each discrete cell at a given site.
4. Collect a representative sample of each of the liquid and solid phases of waste from each discrete cell at a given site if different mud systems were used or where wastes from the "top portion" versus the "deeper section" were segregated.
5. The minimum distance from the edge of the sump at which samples will be obtained is one metre.
6. For sumps less than or equal to 500 m^2 collect samples from five locations. For sumps greater than 500 m^2, sample one location for each 100 m^2 to a maximum of 10 locations. Collect a sample from the entire depth of each of the liquid and solid portions of the waste material at each location.
7. Prepare one composite sample of the liquid phase materials by combining equal volumes of the liquid material collected at each sample location. Follow the same procedure for preparing a composite solid phase sample.

8. The samples should be placed in containers according to the types of analyses to be conducted. Acid washed glass jars with teflon lids are required for samples which will be analyzed for organic components (oil and grease) and Microtox^R bioassay. Clear plastic containers (bags, bottles) are required for samples which will be analyzed to determine inorganic components (salts, metals, pH, others). The plastic should be clear to minimize the potential for sample contamination from colored plastics.

5.5 LIQUID PHASE

1. For sumps with visible hydrocarbons on the surface collect the sample according to the planned disposal procedure - if the hydrocarbon is to be removed prior to disposal do not include the hydrocarbon layer in the sample. If the hydrocarbon will not be removed prior to disposal then include the hydrocarbon layer in the sample.
2. Place portions of the composite liquid sample in containers as follows:
    - a minimum of 2L in a clear plastic container.
    - 1 L in each of 2 acid washed glass jars with teflon lids. Two 1 L jars as opposed to one 2 L jar are required because of the different analyses to be conducted.
3. Stir the composite sample thoroughly and take a field pH measurement using a portable pH meter or pH test strips (Whatman or BDH).
4. Keep the samples at or below 4°C and deliver to the laboratory within 48 hours from the time of sampling. This may necessitate the use of portable coolers and ice in warm weather.

5.6 SOLID PHASE

1. Place a minimum of 2 kg of the composite solid sample in a clear plastic container and fill a 1 L acid washed glass container. If a plastic bag is used, care must be taken to avoid loss of sample (puncture, leakage) and/or obscuring the sample label. Double or triple-bagging is recommended.

5.7 SOIL SAMPLING

If either the liquids or solids or both are to be landspread or landfarmed, the receiving soil must be sampled prior to disposal.

1. For locations where the waste will be spread on and incorporated in the subsoil, obtain one composite sample comprised of equal amounts of 5 subsamples collected from the top 30 cm in the area to be used for disposal.

2. For locations where the waste will be spread on and incorporated in the surface soil or "topsoil" obtain one composite sample comprised of equal amounts of 5 subsamples collected from the 0 to 15 cm depth in the area to be used for disposal.
3. At locations where the "topsoil" has been stockpiled prior to sampling, subsamples must be obtained to represent the entire stockpile.
4. Place a minimum of 2 kg of soil in a clear plastic container or bag. Precautions must be taken to avoid loss of sample or obscuring the identification label. Double-bagging is recommended.

6. DRILLING WASTE ANALYSIS

A prescribed set of analyses outlined in Figure 9 is required to provide the data necessary to develop waste treatment and/or management plans under the requirements of ID-93-1 in Alberta. The data obtained will assist in determining whether landspreading is feasible or confirming the acceptability of alternate disposal options. The analyses listed in sections 6.1 and 6.2 must be conducted to provide data in support of the planning and implementation of drilling waste disposal in Alberta.

A description of the sample preparation procedures and a listing of the analytical parameters to be measured along with the respective reporting units, procedures, and references for all the procedures utilized are provided in Appendix I. Appendix II provides a listing of the analytical parameters that would provide a more detailed characterization of drilling wastes.

6.1 LIQUID PHASE

The liquid phase samples must be analyzed to determine.

1. pH
2. Specific conductance
3. Total suspended solids
4. Nitrogen (nitrate and ammonia)
5. Major ions (Ca, K, Mg, Na, Cl)
6. Sodium adsorption ratio (SAR) by calculation

A toxicity assessment of the liquid phase is essential for the prediction of potential biological impacts of waste disposal. The bio-luminescent bacteria (Microtox^R) test is used in a staged approach to determine the probable causes of toxicity in liquids and to assist in developing waste treatment options.

The bio-luminescent bacteria bioassay is performed using the ERCB Microtox Bioassay Protocol as described in ID-93-1. Reporting units for the test are EC50 (15) values.

6.2 SOLID PHASE

The solid phase samples must be analyzed to determine.

1. Bulk density
2. pH
3. Electrical conductivity (EC)
4. Oil content
5. Major ions (Ca, K, Mg, Na, Cl)
6. Sodium adsorption ratio (SAR) by calculation
7. Metals (B, Cd, Cr, Cu, Ni, Pb, V, and Zn) if:
   a) they were added as part of the drilling mud formulation in excess of the amounts specified in the criteria in ID-93-1;
   b) the well depth is greater than 2300 m; or,
   c) the waste is to be landspread on an area less than 0.75 ha.

For multiple well sumps, or for horizontal wells, metal analysis is required if the total well depth/length is greater than 2300 m.

6.3 SOIL

If the drilling waste is to be landspread or landfarmed the receiving soil samples must be analyzed to determine:

1. pH
2. EC
3. Major ions (Ca, K, Mg, Na, Cl)
4. Sodium adsorption ratio (SAR) by calculation

A field assessment of soil texture is needed to determine the suitability of the receiving soil for landspreading or landfarming.

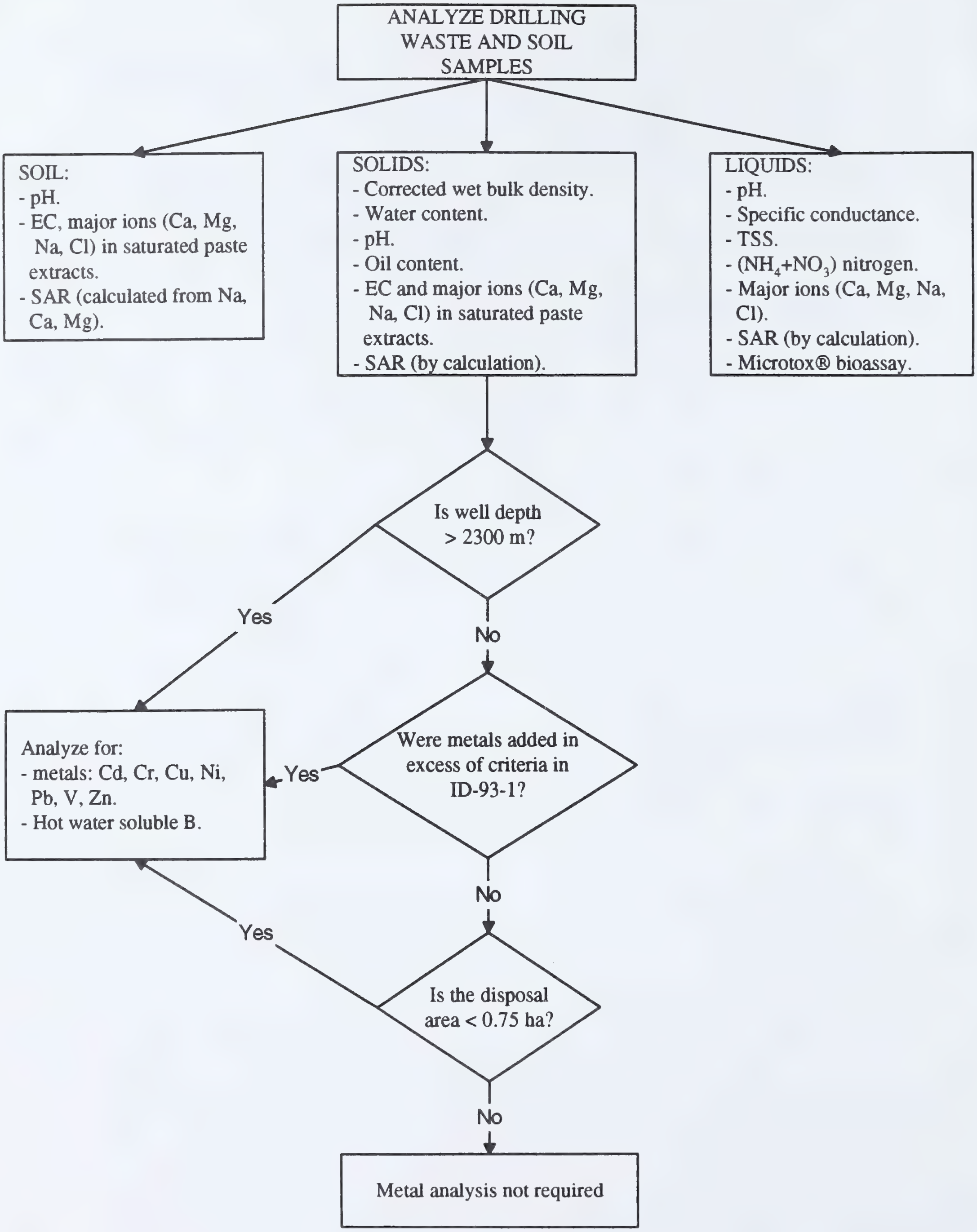

ANALYZE DRILLING WASTE AND SOIL SAMPLES
SOIL:
- pH.
- EC, major ions (Ca, Mg, Na, Cl) in saturated paste extracts.
- SAR (calculated from Na, Ca, Mg).
SOLIDS:
- Corrected wet bulk density.
- Water content.
- pH.
- Oil content.
- EC and major ions (Ca, Mg, Na, Cl) in saturated paste extracts.
- SAR (by calculation).
LIQUIDS:
- pH.
- Specific conductance.
- TSS.
- (NH_4+NO_3) nitrogen.
- Major ions (Ca, Mg, Na, Cl).
- SAR (by calculation).
- Microtox® bioassay.
Is well depth > 2300 m?
Yes
No
Analyze for:
- metals: Cd, Cr, Cu, Ni, Pb, V, Zn.
- Hot water soluble B.
Yes
Were metals added in excess of criteria in ID-93-1?
No
Yes
Is the disposal area < 0.75 ha?
No
Metal analysis not required

Figure 9. Analytical protocols for the drilling wastes and receiving soils.

7. DRILLING WASTE DISPOSAL

As mentioned previously, land-based treatment and disposal procedures represent the final step in a series whereby all efforts to reduce, recycle, and reuse the waste material have been undertaken.

Proper disposal of drilling wastes minimizes any potentially deleterious effects on the environment. These effects may include contamination of surface waters, contamination of groundwater, contamination of the soil rooting zone, reduced internal drainage, and deterioration of soil structure. The main contaminants of concern are hydrocarbons and soluble salts; however certain heavy metals may pose a problem in some of the drilling wastes generated in Alberta. Soil structure deterioration and reduced internal drainage may also result from some of the constituents found in drilling wastes and the disposal techniques employed. Table 6 describes the characteristics of the major soil zones of Alberta and their implications for drilling waste disposal.

Mix, bury and cover and landspreading are the two most commonly used methods of drilling waste disposal in the province.

Monenco Consultants Ltd. (1990) completed a review of the Canadian and selected international literature pertinent to disposal of drilling waste solids. This review also contains a description of burial practices in Alberta.

Figure 10 illustrates the major options available for disposal of liquid and solid phase wastes.

7.1 LIQUIDS

Generally speaking, the liquids component of drilling wastes can be treated, if necessary, prior to final disposal. Disposal options include pumping off (landspreading) on the surrounding land with no subsequent incorporation, combining with the solids material, or deep well disposal. When combined with the solids, disposal options include landspreading and mix, bury and cover.

Surface application of liquids must not result in ponding or runoff, and the total suspended solids (TSS) content must not exceed 10,000 mg/L if the liquid is being applied to vegetation. Where liquids and solids are to be disposed of on the same site, the combined loading rates must not exceed the criteria specified.

"Landspreading while drilling" is a procedure which involves placement of waste material directly in steel tanks or into earthen pits smaller than those that would be used in a conventional sump system (J. Benum, Energy Resources Conservation Board, Wainwright, personal communication). In the majority of cases the cuttings are separated from the remaining waste and then disposed of by mix, bury and cover on lease. The remaining slurry is disposed on large areas of land by a tank truck equipped with nozzles and usually incorporated. Time to incorporation is variable since this procedure is used throughout the year including winter. The maximum application rate allowed, which is currently under review, is 100 barrels/acre (about 35 m^3/ha)

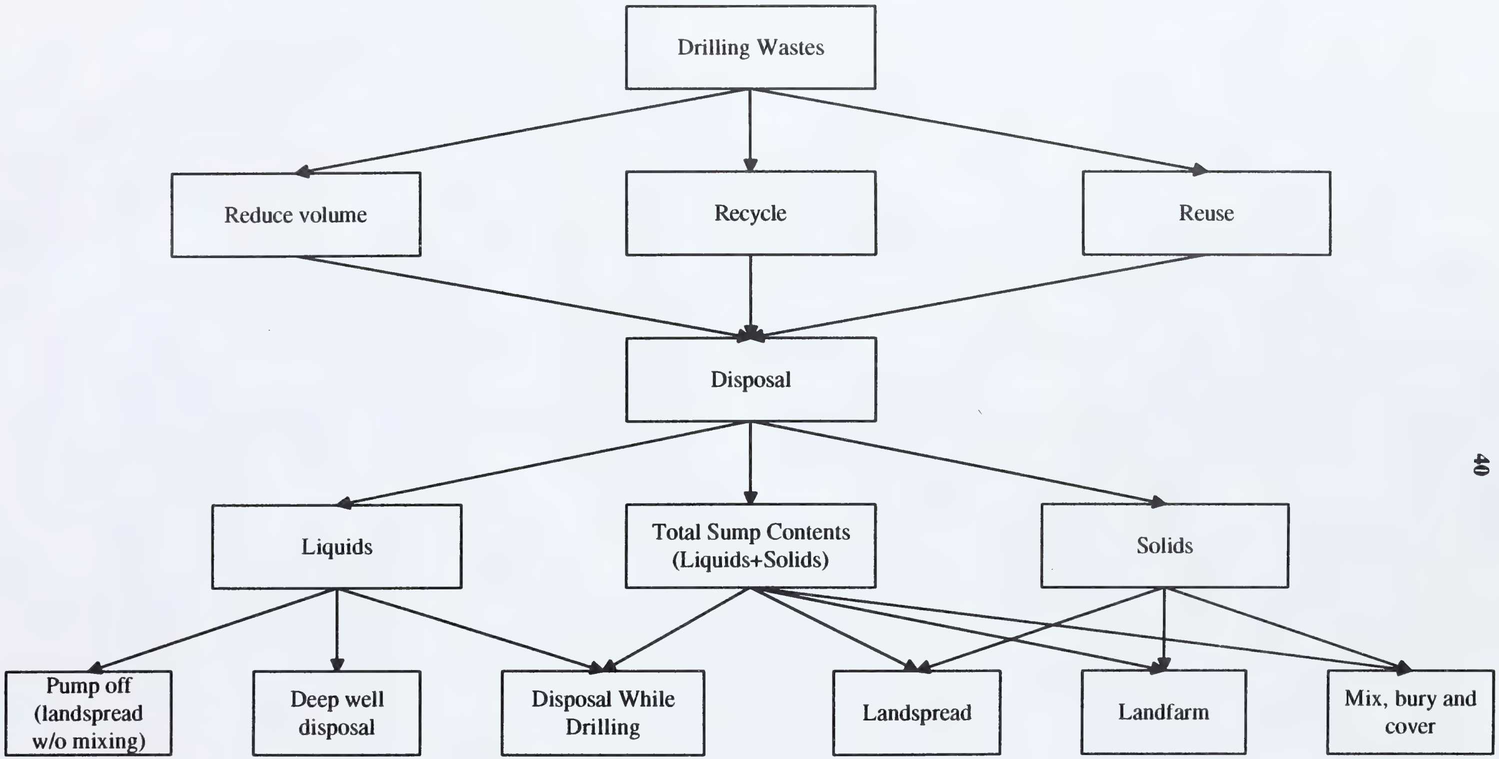


Figure 10. Major options used for liquid and solid phase drilling waste disposal

Table 6. Characteristics of the Soil Zones (Major Soils) in Alberta and Their Implications for Drilling Waste Disposal and Site Reclamation.

Soil Zone/Major Soil	Climate		Implications for Waste Disposal and Reclamation
BROWN • thin (5-15 cm) brown surface horizon • low organic matter content (2%) • pH neutral to alkaline • high base saturation • low to moderate salinity	Semi-arid:	Annual precipitation average 300 mm.	• high wind erosion hazard • dry conditions reduce rates of biological decomposition • establishment of vegetation is difficult • minimum amount of leaching
	Summer:	Low rainfall, very warm temperatures, frequent high winds.	
	Winter:	Cold temperatures, winds and snow storms with appreciable snow accumulation at times. Periodic warm Chinook winds. Variable frost depth.	
DARK BROWN • 10-20 cm dark brown surface horizon • 4% organic matter slightly acid to neutral • high base saturation • low to moderate salinity	Semi-arid:	Annual precipitation averages 350 mm.	• generally slightly more favorable than Brown Zone
	Summer:	same as Brown Soil Zone	
	Winter:	same as Brown Soil Zone	
BLACK • 25-35 cm black surface horizon • 8% organic matter • acid to neutral • high base saturation • low salinity	Dry-Subhumid:	Annual precipitation averages 380 mm in the SE corner and 460 mm in the north and west.	• most favorable summer climate for biological decomposition • relatively easy to establish vegetation • soil leaching occurs readily
	Summer:	Ample rainfall, warm to cool temperatures, occasional heavy and prolonged rainfall.	
	Winter:	Cold temperatures, frost depth significant.	
DARK GRAY • 10-15 cm dark gray surface horizon • organic matter content less than for Black • otherwise similar	Similar to Black		• similar to Black zone

continued ...

Table 6. Concluded.

Soil Zone/Major Soil	Climate		Implications for Waste Disposal and Reclamation
GRAY • thin leaf litter overlying a brown to gray platy horizon (Ae) and finer textured • strongly structured B horizon • low fertility • moderate to strong acidity • high base saturation • low salinity	Subhumid: Summer: Winter:	Annual precipitation varies from 480-560 mm in the SW to as for Black Zone as for Black Zone	• must salvage as much topsoil as possible to enhance decomposition and improve seedbed. • Fertilization recommended • high runoff potential
UNDIFFERENTIATED MOUNTAIN COMPLEX Brunisolic, Luvisolic and Regosolic Soils • thin leaf litter overlying a brown to gray mineral horizon • shallow with significant stony soils • coarse fragment component • low fertility • low salinity	Humid: Summer: Winter:	Annual precipitation averages over 600 mm. High rainfall and cool temperatures; occasional heavy and prolonged rainfall. Cold temperatures with deep snow accumulation. Periodic warm Chinook winds.	• similar to Gray Zone but higher potential for runoff, erosion and surface water

(J. Benum, Energy Resources Conservation Board, Wainwright, personal communication).

7.2 SOLIDS

The most common methods of drilling waste solids disposal include mix, bury and cover, and landspreading. Other methods include landspreading while drilling and road spreading. Landfarming is often used for specific waste types such as diesel invert wastes.

7.2.1 Mix, Bury And Cover

Mix, bury and cover is a method whereby sump solids are diluted by mixing with subsoil and stabilized (dry and firm to ensure no future subsidence). The waste materials are mixed at least 1:1 by volume with the subsoil. The subsoil-waste mixture is then placed into the original sump, or other sumps or pits and is covered with at least one metre of clean subsoil and the original topsoil. The criteria related to this type of disposal include the following.

1. The base of the final waste/soil mixture must be at least 1 m above the water table or a layer of permeable material.
2. Oil and grease must be less than 0.1 percent in the soil/waste mix.
3. The soil/waste mix pH must be between 6.5 and 8.5.
4. Less than 1600 kg of Cl can be buried at a disposal site and the concentration in the waste material must not exceed 2000 mg Cl/kg dry solids.
5. Where analysis for metals is required, metal content of the waste buried at a site shall not exceed"
   - 10 kg boron
   - 3 kg cadmium
   - 200 kg chromium
   - 400 kg copper
   - 200 kg lead
   - 50 kg nickel
   - 200 kg vanadium
   - 600 kg zinc
6. If liquids are buried with solids, nitrogen (ammonia plus nitrate - N) must be less than 400 kg.

7.2.1.1 Mix, bury and cover implementation: There are a number of practices and conditions that contribute to a successful and effective mix, bury and cover operation. This procedure is generally used after liquids have been removed and properly disposed. The liquids may be disposed with the solids provided that the mixing results in a stable material. Disposal is based on the characteristics of the combined liquid and solid slurry.

The first step in the disposal process is to ensure that the characteristics of the waste (solids only or liquid/solid slurry) meet the criteria described above.

The disposal operations must be completed under adequately dry conditions so that the impact on the site is minimized and a uniform mix is achieved. The resulting soil and waste mix must be capable of supporting the movement of heavy equipment without subsidence.

The replacement of the one metre of clean subsoil must be done under adequately dry conditions to minimize compaction and deterioration of physical properties at the site. The topsoil or coversoil material must also be replaced under adequately dry conditions to minimize compaction and care must be taken to minimize mixing of the topsoil with the subsoil below.

7.2.2. Landspreading

Landspreading involves spreading waste over a pre-determined land area based on an acceptable loading rate. Landspreading is usually done for wastes containing elevated levels of heavy metals and/or salts, and involves **a single** application. The goal of landspreading is to dispose of the waste in a manner that preserves soil chemical, biological, and physical properties. The spread or loading rate for a waste must be based on the most limiting analyte in the waste or soil/waste mix. Criteria for landspreading include the following.

1. A maximum of 10 cm of waste solids should be applied to ensure complete mixing of the waste and the receiving soil, and to minimize potential effects on soil physical properties.
2. The waste is to be thoroughly mixed into the soil at a 1:3 waste/soil ratio to (e.g., a maximum of 10 cm of waste mixed into 30 cm of soil).
3. The pH of the soil/waste mix must be between 6.5 and 8.5; for forest soils with an initial pH of 6.5 or lower the increase in pH of the soil/waste mix must not exceed 1.5 units.
4. Oil and grease content of the soil/waste mix must be less than 0.5% in the upper 20 cm (topsoil) and less than 0.1% in the subsoil below; if these levels are exceeded a disposal plan will be required which addresses degradation of the hydrocarbon component of the waste.
5. EC of the soil/waste mix must not exceed 4 dS/m or, where the initial soil EC is more than 4 dS/m, the soil/waste mix can be up to 1 dS/m higher than the initial soil EC.
6. SAR of the soil/waste mix must be less than 10 or, where the original soil SAR is more than 10, the soil/waste mix must not exceed the initial SAR by more than 1 unit.
7. Chloride addition to the soil must not exceed 800 kg/ha.
8. Where metals analysis is required, metal addition must not exceed the following rates:
    - 5 kg/ha boron
    - 1.5 kg/ha cadmium
    - 100 kg/ha chromium
    - 200 kg/ha copper
    - 100 kg/ha lead
    - 25 kg/ha nickel
    - 100 kg/ha vanadium
    - 300 kg/ha zinc

Specific landscape features and soil properties vary in their suitability for landspreading or landfarming (Tables 2 and 6). The principles pertaining to suitability are the same as for sump placement, with stricter slope guidelines to control runoff, and additional guidelines to ensure that soil chemical properties are acceptable.

Solonetzic soils suggest a potential salinity problem so caution must be exercised as landspreading can make an existing salinity problem worse.

Gleysolic soils indicate very wet soil conditions for a substantial portion of the year; such areas are not suitable for siting sumps or sump disposal because of the high water table and very poor drainage.

Luvisolic soils indicate a moderate leaching environment, which is good for landspreading as soluble salts will be leached below the "topsoil" in a few years (Macyk et al. 1992a,b).

Chernozemic soils are also generally good sites for landspreading and are usually characterized by deep, rich topsoil with ample microbial activity.

Alkaline soils are not well suited to waste disposal because the generally high pH values associated with drilling wastes can increase soil alkalinity.

There are two basic approaches to landspreading drilling waste materials. The wastes can be spread and incorporated into the subsoil prior to topsoil replacement, or applied and incorporated into the surface after topsoil replacement. Both approaches offer advantages and disadvantages.

7.2.2.1 Landspreading in the subsoil. Landspreading in the subsoil involves spreading of the waste on the "working" surface of a well site or designated waste receiving area and then incorporating the waste. This practice offers the following advantages.

1. Topsoil is not "diluted" and generally not impacted by the addition of waste. It is still impacted by the removal and subsequent replacement.
2. There is less potential for waste materials to move off site due to excessive moisture and runoff;
3. Landowners generally favour disposal into this horizon.

Landspreading in the subsoil offers the disadvantage that poor mixing or incorporation can result in physical problems such as barriers to moisture movement and root penetration.

7.2.2.2 Landspreading in the surface soil. Landspreading in the surface soil involves placement and incorporation of the waste in the replaced surface soil or undisturbed topsoil. This practice offers the following advantages.

1. Can improve the physical characteristics of some surface soils particularly those found in forested areas (Brunisols, Luvisols). This enhancement of characteristics can

result in improved porosity, water holding capacity, rooting characteristics and therefore the yield of some crops (Macyk et al. 1992b).

2. Can improve the chemical characteristics of some surface soils, particularly those found in forested areas (Brunisols, Luvisols). For example, acid pH conditions can be ameliorated where appropriate and the wastes can provide various macronutrients and micronutrients which can result in enhanced plant growth, yield, and trace element levels in the tissue (Macyk et al. 1989; 1992b).

Landspreading in the surface soil offers the following disadvantages.

1. The surface soil is diluted to some extent.
2. Addition of wastes with certain characteristics such as high clay content can cause physical problems.
3. Waste material components can be moved offsite during periods of high rainfall and resulting runoff and erosion.
4. Mixing depth must be carefully controlled to ensure that subsoil is not brought up into the surface soil.
5. Surface soils may not be deep enough (<30 cm) to allow maximum application of wastes (10 cm).
6. Mixing of drilling waste into topsoil on private land will generally not be acceptable, and will likely result in failure to obtain a reclamation certificate.

7.2.2.3 Landspreading implementation. There are a number of practices and conditions that contribute to a successful and effective landspreading operation. Again, the principle of landspreading/landfarming is that the waste constituents (hydrocarbons, salts, other) are spread over a large enough area that they are degraded and/or assimilated and do not pose a risk to soil, vegetation or groundwater.

The first step in the process is to determine disposal rate based on the waste characteristics and volume and characteristics of the receiving soil.

Winter disposal should be avoided because the waste can't be readily incorporated into the soil and there is a potential for surface water contamination. The application and incorporation should be completed under adequately dry conditions so that the impact on the site is minimized and a uniform spread and incorporation is achieved.

1. Waste can be applied by a variety of pieces of equipment including farm spreader, grader or other appropriate equipment that is suitable for a given location and will result in a uniform application.
2. The waste should be dried to extent possible and then incorporated as uniformly as possible. Incorporating wastes in subsoil and soil parent materials is generally more difficult than incorporation in topsoil simply because the subsoil represents the

working surface of the site which is generally somewhat more compacted and finer textured than the surface soil which is replaced. Incorporation of the waste requires appropriate equipment. Rototilling is the best method for incorporating wastes; harrowing, discing or ploughing may not result in thorough waste incorporation and may leave "pockets" of waste in the soil.

3. For waste applications of 8 to 10 cm it is advisable to apply approximately one-half of the material and incorporate and then apply the remainder followed by incorporation.
4. When required fertilizer should be applied prior to rototilling so that nutrients will be well mixed into the waste - treated layer and so that volatilization of ammonia nitrogen is minimized.

7.2.3 Landfarming

Landfarming is a waste treatment/disposal method whereby a single or multiple applications of biodegradable wastes are made on a dedicated parcel of land which is managed in a manner to allow the soil system to degrade, transform, and assimilate the waste constituents. This practice offers the advantages of promoting decomposition of specific components such as hydrocarbons and allows for multiple applications and periodic tilling. Landfarming of wastes with elevated oil and grease levels (hydrocarbon based systems) requires approval of a site disposal and management plan submitted to the appropriate regulatory agency. This plan must be submitted as part of the well application to the ERCB.

Although the hydrocarbon component is generally considered to be biodegradable, experience indicates that considerable care and management are required to promote the necessary biological activity under Alberta's soil and climatic conditions. Research has shown that the hydrocarbon component in these wastes degrades more rapidly if applied at oil and grease levels of about 1% in soil per application in a multiple application scenario as compared to single and higher rate applications (Macyk et al. 1992a; Pojasok et al. 1992).

8. LAND APPLICATION OF SOLID AND LIQUID PHASE DRILLING WASTES

Land application of drilling wastes to either surface or subsurface soils requires the calculation of appropriate disposal rates that ensure the protection of the soil resource and the surrounding media (e.g., air, groundwater, surface water, and plant and animal communities). Knowledge of the waste application rates leads to simple calculations of the minimum area required for disposal of the waste and furthermore the maximum thickness of waste application. All the above calculations depend on the waste and receiving soil characteristics, waste volumes, and regulatory limits. Details of the required calculations for both the solid and liquid wastes are included in this section.

Table 7 provides a glossary of terms used in the calculation of waste application rates and areas required for disposal in this section of the manual. Limits regarding several analyte application rates $\left(\frac{kg\ i}{ha}\right)$ and the resultant EC, pH and SAR of the post application soil-waste mixture are described in Table 8.

8.1 SOLID PHASE CALCULATIONS

8.1.1 Land Application

The following equations are used to calculate the application rates (R), areas required for application (A) and waste layer thickness (D). These can be used for the solid waste analytes (except pH) by substituting analyte values where appropriate.

i. The solid waste concentration of analyte i (except for Cl) obtained from the analytical laboratory as C_{si} $\left(\frac{mg\ i}{kg\ dry\ solids}\right)$ is converted to another unit $\left(\frac{kg\ i}{kg\ dry\ solids}\right)$ in the following manner:

$$C_{si}\left(\frac{kg\ i}{kg\ dry\ solids}\right) = C_{si}\left(\frac{mg\ i}{kg\ dry\ solids}\right) * 10^{-6}\left(\frac{kg\ i}{mg\ i}\right)$$

Table 7. Glossary of Terms Used in the Calculation of Waste Application Rates and Areas Required for Disposal.

EC = Electrical Conductivity measured in liquids or saturated paste extracts $\left(\frac{dS}{m}\right)$.

SAR = Sodium Adsorption Ratio, calculated from soluble Na, Ca, and Mg concentrations.

P = Saturation content of the saturated paste $\left(\frac{L}{kg\ dry\ solids}\right)$.

L_i = Regulatory limit for the application of wastes containing analyte i $\left(\frac{kg\ i}{ha}\right)$.

C_{si} = Concentration of analyte i in the solid waste material $\left(\frac{mg\ i}{kg\ dry\ solids}\right)$.

ρ_{bw} = Wet Bulk Density of the waste material $\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right)$.

R_{si} = Maximum Solid Waste Application Rate based on analyte i $\left(\frac{m^3\ wet\ solids}{ha}\right)$.

A_{si} = Minimum Allowable Area required to apply the solid waste material based on analyte i (ha).

D_{si} = Maximum Allowable Thickness of the applied solid waste material based on analyte i (cm).

V_s = Volume of the solid waste material (m^3 wet waste).

ρ_s = Specific density of the solid material $\left(\frac{g}{cm^3}\right)$.

ρ_w = Specific density of water $\left(\frac{g}{cm^3}\right)$.

ρ_o = Specific density of oil $\left(\frac{g}{cm^3}\right)$.

θ_m = Water content of the wet solid waste material $\left(\frac{kg\ water}{kg\ dry\ solids}\right)$.

θ_o = Oil content of the wet solid waste material $\left(\frac{kg\ oil}{kg\ dry\ solids}\right)$.

V_l = Volume of the liquid waste material (m^3).

C_{li} = Concentration of analyte i in the liquid waste material $\left(\frac{mg\ i}{L}\right)$.

R_{li} = Maximum Application Rate of liquid waste material based on analyte i $\left(\frac{m^3}{ha}\right)$.

A_{li} = Minimum Allowable Area required to apply the liquid waste material based on analyte i (ha).

D_{li} = Maximum Allowable Thickness of the applied liquid waste material based on analyte i (cm).

R_{sli} = Maximum Application Rate of solid plus liquid waste material based on analyte i $\left(\frac{m^3\ waste}{ha}\right)$.

A_{sli} = Minimum Allowable Area required to apply the solid plus liquid waste material based on analyte i (ha).

Table 8. Limits for the Land Application of Various Analytes. (From ID-93-1, ERCB 1993).

Parameter	Limit $\left(\frac{kg}{ha}\right)$
Boron	5
Cadmium	1.5
Chloride	800
Chromium	100
Copper	200
Lead	100
Nickel	25
Nitrogen (NH_4+NO_3) - N	400
Sodium[a]	500
Vanadium	100
Zinc	300
Sodium	500
pH[b]	6.5 - 8.5[c]
EC[b]	4 $\frac{dS}{m}$[d]
SAR[b]	10[e]

[a] This analyte is not included in the ERCB (1993) guidelines.

[b] Based on predicted properties of the post application soil-waste mix.

[c] For forest soils with pH < 6.5, this limit is set to the soil pH + 1.5.

[d] If the soil EC is >4, then the limit is set to soil EC + 1.

[e] If the soil SAR is > 10, then the limit is set to soil SAR + 1.

Chloride concentrations in the saturated paste extracts obtained as $\left(\frac{mg\ Cl}{L}\right)$ from the analytical laboratory, are converted to $\left(\frac{kg\ Cl}{kg\ dry\ solids}\right)$ using the saturation content of the saturated paste (P) in the following manner:

$$C_{Cl}\left(\frac{kg\ Cl}{kg\ dry\ solids}\right) = C_{Cl}\left(\frac{mg\ Cl}{L}\right) * P\left(\frac{L}{kg\ dry\ solids}\right) * 10^{-6}\left(\frac{kg\ Cl}{mg\ Cl}\right)$$

ii. The solid waste wet bulk density $\rho_{bw}\left(\frac{g\ dry\ solids}{cm^3\ wet\ solids}\right)$ is converted to another unit $\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right)$ in the following manner:

$$\rho_{bw}\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right) = \rho_{bw}\left(\frac{g\ dry\ solids}{cm^3\ wet\ solids}\right) * 10^3$$

The wet bulk density is either measured from the weight of the dry waste and the volume of the wet waste, or calculated from the water content, oil content and an assumed solids density of 2.6 $\frac{g}{cm^3}$. The equation for the wet bulk density (ρ_{bw}) is developed as follows (assuming that the samples' pore spaces are water and/or oil saturated):

$$\rho_{bw} = \frac{M_s + M_o}{V_s + V_w + V_o}$$

Where **M_s** and **V_s** are the weight (g) and volume (cm^3) of the solids,

M_w and **V_w** are the weight (g) and volume (cm^3) of the water, and

M_o and **V_o** are the weight (g) and volume (cm^3) of the oil.

Furthermore, the solids density (ρ_s), water density (ρ_w), oil density (ρ_o), water (θ_m) and oil (θ_o) contents are defined as:

$$\rho_s = \left(\frac{M_s}{V_s}\right) = 2.6\ \frac{g}{cm^3},\quad \rho_w = \left(\frac{M_w}{V_w}\right) = 1\ \frac{g}{cm^3},\quad \rho_o = \left(\frac{M_o}{V_o}\right) = 0.9\ \frac{g}{cm^3}$$

and

$$\theta_m \left(\frac{g\ water}{g\ solids}\right) = \left(\frac{M_w}{M_s}\right),\quad \theta_o \left(\frac{g\ oil}{g\ solids}\right) = \left(\frac{M_o}{M_s}\right)$$

Substituting the above into the ρ_{bw} equation leads to the following equation for ρ_{bw}:

$$\rho_{bw} = \left(\frac{1+\theta_o}{\theta_m + \left(\frac{1}{\rho_s}\right) + \left(\frac{\theta_o}{\rho_o}\right)}\right) = \left(\frac{1+\theta_o}{\theta_m + \left(\frac{1}{2.6}\right) + \left(\frac{\theta_o}{0.9}\right)}\right)$$

Therefore one requires only the water and oil contents (measured for all solid waste samples) in order to calculate the wet bulk density.

If the oil content is assumed negligible (i.e < 1%), then the above equation for ρ_{bw} is reduced to:

$$\rho_{bw} = \left(\frac{1}{\theta_m + (0.38)}\right)$$

If the water content $\theta_m \left(\frac{g\ water}{g\ solids}\right)$ and oil content $\theta_o \left(\frac{g\ oil}{g\ solids}\right)$ are expressed in (%) units, then the $\rho_{bw} \left(\frac{g\ dry\ solids}{cm^3\ wet\ solids}\right)$ is expressed as:

$$\rho_{bw} = \left(\frac{1 + \left(\frac{\theta_o}{100}\right)}{\left(\frac{\theta_m}{100}\right) + (0.38) + \left(\frac{\theta_o}{100}\right)} \right)$$

or for low oil contents (<1%)

$$\rho_{bw} = \left(\frac{1}{\left(\frac{\theta_m}{100}\right) + (0.38)} \right)$$

iii. The solid waste application rate based on analyte i (R_{si}) is calculated from the regulatory limit for i (L_i) and the waste characteristics C_{si} and ρ_{bw} as follows:

$$R_{si}\left(\frac{m^3 \text{ wet solids}}{ha}\right) = \frac{L_i\left(\frac{kg\ i}{ha}\right)}{Cs_i\left(\frac{kg\ i}{kg \text{ dry solids}}\right) * \rho_{bw}\left(\frac{kg \text{ dry solids}}{m^3 \text{ wet solids}}\right)}$$

iv. The area required for waste application based on waste component i (A_i(ha)) is calculated as:

$$A_{si}\ (ha) = \frac{V_s\ (m^3 \text{ wet solids})}{R_{si}\left(\frac{m^3 \text{ wet solids}}{ha}\right)}$$

v. The thickness of the applied layer based on waste component i (D_i (cm wet waste)) is calculated as:

$$\boldsymbol{D_{si}}\ (cm\ wet\ solids) = \frac{\boldsymbol{V_s}\ (m^3\ wet\ solids)}{\boldsymbol{A_{si}}\ (ha) * 10^4 \left(\frac{m^2}{ha}\right)} \times 10^2 \left(\frac{cm}{m}\right)$$

or

$$\boldsymbol{D_{si}}\ (cm\ wet\ solids) = \boldsymbol{R_{si}} \left(\frac{m^3\ wet\ solids}{ha}\right) * 10^{-4} \left(\frac{ha}{m^2}\right) * 10^2 \left(\frac{cm}{m}\right)$$

D_{si} is limited to 10 cm (ERCB 1993) when the waste is landspread and mixed into 30 cm of soil.

vi. The appropriate rates of waste disposal based on pH, EC, and SAR limits could be approximated experimentally for a given waste and its receiving soil, calculated from some empirical equations derived from soil and waste mixing experiments, or approximated by using a Na application limit (EC and SAR only).

The experimental procedures consist of incubating and mixing the same weight of receiving soil with increasing amounts of waste materials for an appropriate time required to establish chemical equilibrium. At the end of th incubation period, the chemical properties (pH, EC and SAR) of the various soil-waste mixtures are measured and plotted against the waste to soil ratios used. The appropriate rates are then calculated from the limit pH, EC or SAR achieved at a given soil-waste ratio (application rate). An example of this approach is as follows:

1. Weigh air dry sieved (<2 mm) soil (e.g., 100 g) into plastic containers (500 mL or 1 L).

2. Add increasing amounts of the waste (e.g., 10, 20, 30 g) considered to the above soil. The maximum wast addition should always be less than a third of the soil weight above.

3. Add water to saturation and incubate at room temperature for the time it takes to reach equilibrium (at leas overnight).

4. At the end of incubation, measure the pH of the soil-waste mix, and the EC and ions (Ca, Mg, and Na) in the extract of the soil-waste mix. Calculate the SAR from the extract Ca, Mg, and Na data.

5. Plot the pH, EC and SAR of the soil-waste mix (y axis) vs the waste to soil ratio (converted to kg/ha). The conversion of waste to soil ratio to an application rate (kg/ha) is done as follows:

$$\boldsymbol{R}\left(\frac{kg\ dry\ solids}{ha}\right) = \left(\frac{g\ dry\ solids}{g\ soil}\right) x \left(\frac{2\ x\ 10^{9}\ g\ soil}{ha}\right) x \left(\frac{10^{-3}\ kg}{g}\right)$$

6. At the appropriate regulatory limits for pH, EC, and SAR (Table 8) on the y-axis, draw a line parallel to the x-axis to intersect the curve plotted above. Read the x-axis point corresponding to this intersection $\left(\frac{kg\ dry\ solids}{ha}\right)$ and convert to a waste application rate $\left(\frac{m^3\ wet\ solids}{ha}\right)$ using the wet bulk density (ρ_{bw}) in the following manner:

$$\boldsymbol{R}\left(\frac{m^3\ wet\ solids}{ha}\right) = \left(\frac{\boldsymbol{R}\left(\frac{kg\ dry\ solids}{ha}\right)}{\boldsymbol{\rho_{bw}}\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right)}\right)$$

Calculation of areas required and thicknesses of the application layer are then performed as previously shown.

The prediction of the resultant (limit) EC and SAR of the soil-waste mixture from the corresponding values for the individual soil and waste considered is illustrated and derived in the following section. Firstly, it is assumed that one can calculate the resultant EC and SAR values for soil-waste mixtures from the EC and SAR values of the individual components (soils and wastes). This 'mixture' model assumes that the contribution of each component to the mix is proportional to its intrinsic value (EC or SAR) and its weight in the mix. In this model one creates two equations with two unknowns (weight of waste and soil in the mix) each and solves them for the desired unknown (e.g., weight of waste in the mix, or application rate). EC is used as an example to illustrate this calculation.

One can assume that a hectare furrow slice (a volume corresponding to an area of 1 ha and a depth of 15 cm that weighs approximately 2,000,000 kg at a bulk density of 1.3 g/cm^3) of soil-waste mix is proportionally made up of X amount of waste and Y amount of soil, such that:

$$X + Y = 1$$

$$\text{Where } X = \left(\frac{\text{waste weight (kg)}}{\text{ha soil-waste mix (kg)}}\right) = \left(\frac{\text{waste weight (kg)}}{2x10^6\ \text{kg}}\right)$$

Y is similarly defined for soil.

One can assume that the resultant EC (EC_c) of the soil-waste mix can be calculated from the soil EC (EC_s) and waste EC (EC_w) as follows:

$$EC_c = X \,.\, EC_w + Y \,.\, EC_s$$

Solving the above two equations for X_{EC} (i.e. X based on EC values) results in:

$$X_{EC} = \frac{EC_c - EC_s}{EC_w - EC_s}$$

and similarly for SAR, one obtains:

$$X_{SAR} = \frac{SAR_c - SAR_s}{SAR_w - SAR_s}$$

Limits for EC_c and SAR_c are set at 4 $\frac{dS}{m}$ and 10 respectively, or 1 unit higher than the soil values if the soil is already at or higher than these limits. Therefore, X_{EC} and X_{SAR} can be calculated from the EC and SAR values of the waste and soil samples only. The application rates (R_{EC} and R_{SAR}), areas required (A_{EC} and A_{SAR}) and waste layer thicknesses (D_{EC} and D_{SAR}) can be calculated from the X values (for both EC and SAR limits) as follows:

$$\boldsymbol{R}\left(\frac{m^3\ wet\ solids}{ha}\right) = \left(\frac{\boldsymbol{X}\left(\frac{kg\ dry\ solids}{kg\ waste\text{-}soil\ mix}\right)\left(\frac{2x10^6\ kg\ waste\text{-}soil\ mix}{ha}\right)}{\boldsymbol{\rho_{bw}}\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right)}\right)$$

$$\boldsymbol{A}\ (ha) = \left(\frac{\boldsymbol{V_s}\ (m^3\ wet\ solids)}{\boldsymbol{R}\left(\frac{m^3\ wet\ solids}{ha}\right)}\right)$$

$$\boldsymbol{D}\ (cm\ wet\ solids) = \left(\frac{\boldsymbol{V_s}\ (m^3\ wet\ solids)}{\boldsymbol{A}\ (ha) x10^4\ (\frac{m^2}{ha})}\right) x\ 10^2\ (\frac{cm}{m})$$

The calculated EC and SAR values for the soil-waste mix were slightly modified to fit empirical relationships between calculated and experimentally measured values as described below. Initially one can assume that the calculated EC_c and SAR_c values for the soil-waste mix are similar to the measured values after waste application and mixing (EC_m and SAR_m), or:

$\mathbf{EC_m = EC_c}$, and $\mathbf{SAR_m = SAR_c}$

Linear equations for EC_m vs EC_c and SAR_m vs SAR_c were calculated using the soil, waste, and soil-waste mix EC and SAR data for three greenhouse studies of drilling wastes impacts on Alberta soils reported by Macyk et al. (1989) . These equations were forced through the origin (i.e., calculated and mixture values are both 0 at the same time), and were found to be (Figures 11 and 12):

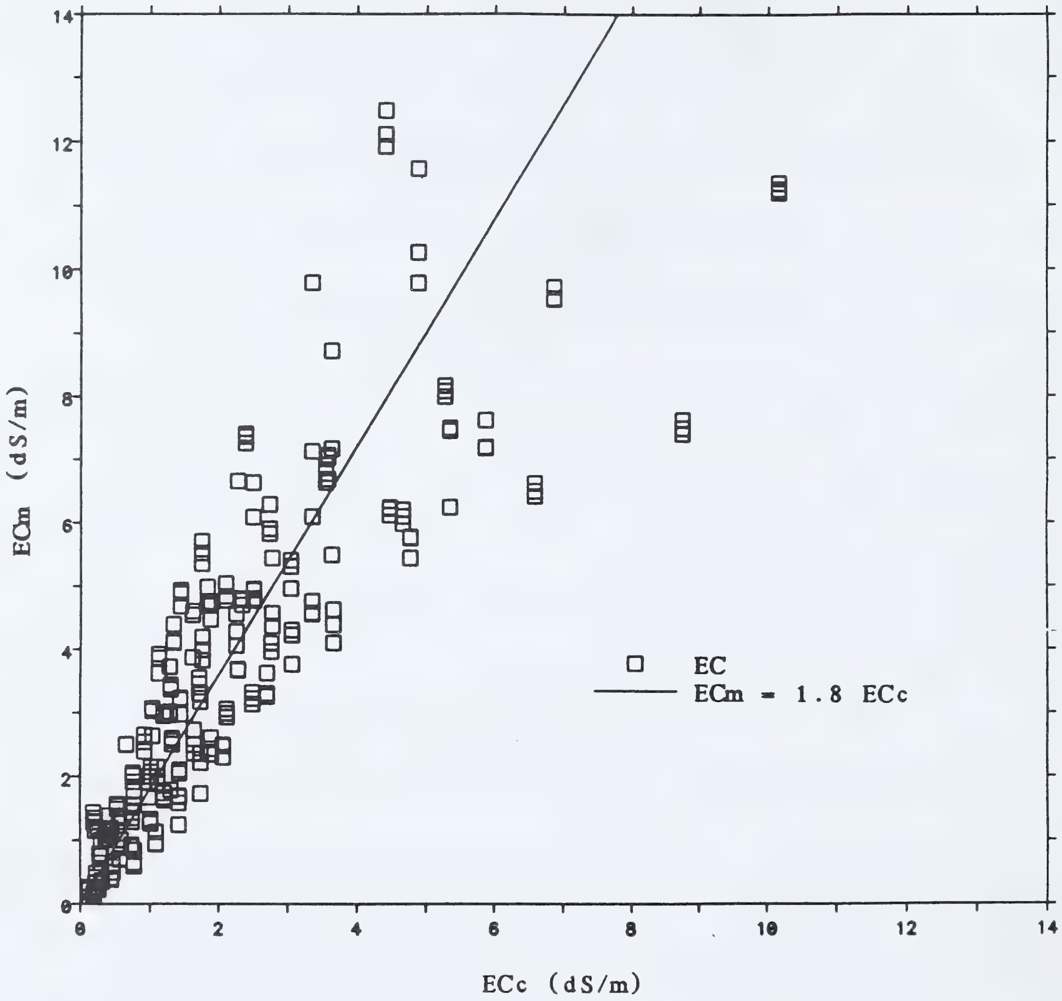


Figure 11. Measured vs calculated EC for three pot trial soils.

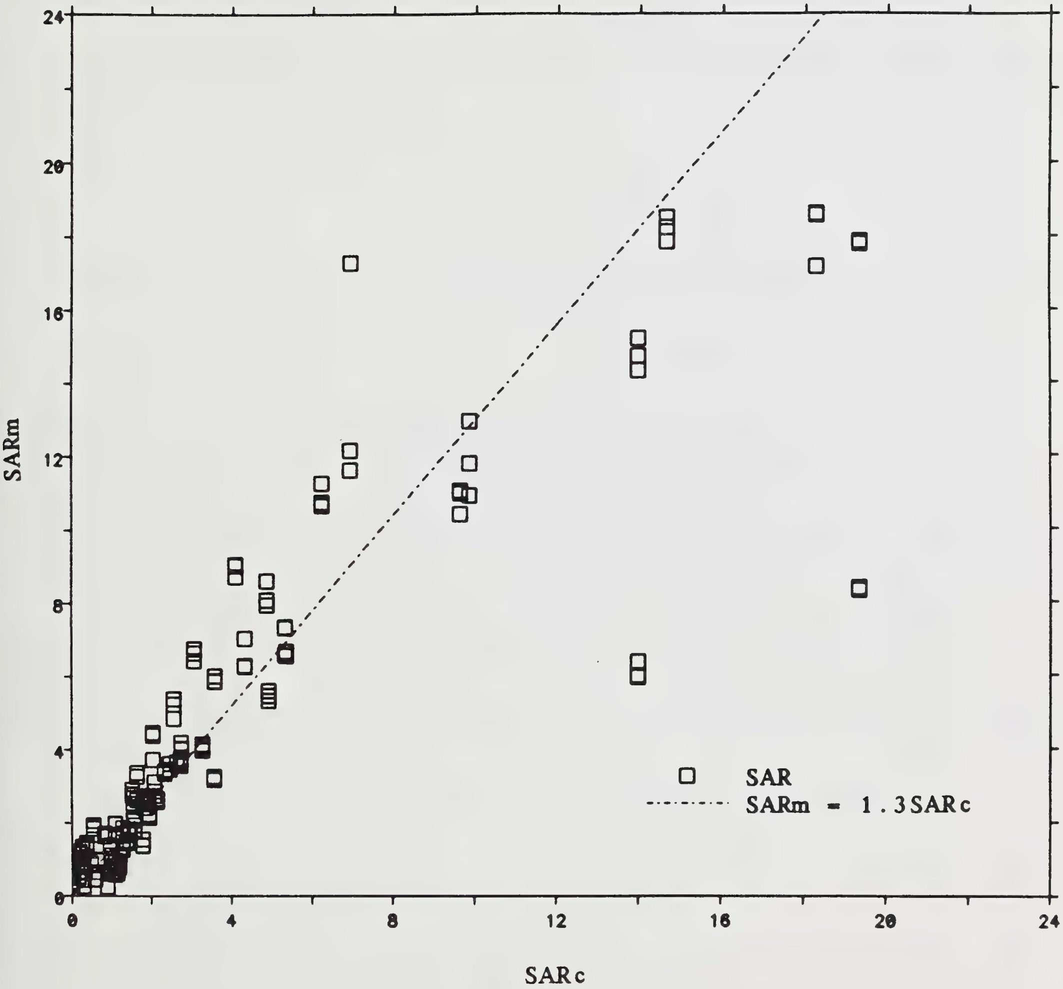


Figure 12. Measured vs calculated SAR for three pot trial soils.

$$\boldsymbol{EC_m} = 1.8\ \boldsymbol{EC_c}.\ At\ \boldsymbol{EC_m} = 4\ \frac{dS}{m}\ ,\ \boldsymbol{EC_c} = 2.22\ \frac{dS}{m}$$

and

$$\boldsymbol{SAR_m} = 1.3\ \boldsymbol{SAR_c}.\ At\ \boldsymbol{SAR_m} = 10,\ \boldsymbol{SAR_c} = 7.69$$

The above equations are summarized in Table 9.

One can also use sodium application rates as a surrogate for both EC and SAR calculations. According to an Alberta Environment (1987) report, the addition of slaughterhouse wastewater to a medium textured soil increased soil E by 1.5 $\frac{dS}{m}$ and SAR by 2.5 for each addition of 200 $\frac{kg\ Na}{ha}$. If one accepts the above, then the increase in soil EC and SAR from pre application values to 4 $\frac{dS}{m}$ and 10 (limits after application) can be approximated with sodium application rates that are calculated accordingly. If one assumes that the soil has an EC of 0.5 and an SAR of 1, then th corresponding Na application rates are approximately 500 and 720 $\frac{kg}{ha}$ respectively. A sodium limit of 500 $\frac{kg}{ha}$ (for a non saline, non sodic, medium textured soil) can be chosen as a surrogate for EC and SAR calculations.

8.1.2 Mix, Bury and Cover

The calculations required for determining the applicability of this option for waste disposal involve both the tota loading (kg/site) of several elements (Section 7.2.1) and the concentrations of Cl and oil in the resultant soil-waste mix. The total loadings are compared to the allowed regulatory limits (Section 7.2.1) in order to determine if the waste could be disposed of on site using mix, bury and cover. The regulated concentrations of Cl and oil in the resultant soil-waste mix could be used to give an estimate (approximation) of the minimum soil:waste ratio needed.

Table 9. Calculation of application rate, required area and thickness of an applied solid waste layer.

Parameter	Soil	Waste	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	EC_s	EC_w	$\left(\frac{EC_L-EC_s}{EC_w-EC_s}\right)\frac{2000}{\rho_{bw}}$, $EC_L=4$ or (EC_s+1)	V/R	R/100
Na (mg/L)	Na_s	Na_w	$\left(\frac{500x1000}{Na_wP_w\rho_{bw}}\right)$	V/R	R/100
SAR	SAR_s	SAR_w	$\left(\frac{SAR_L-SAR_s}{SAR_w-SAR_s}\right)\frac{2000}{\rho_{bw}}$, $SAR_L=10$ or SAR_s+1	V/R	R/100
Cl (mg/L)	Cl_s	Cl_w	$\left(\frac{800x1000}{Cl_wP_w\rho_{bw}}\right)$	V/R	R/100
Saturation (L/kg)	P_s	P_w			
Oil Content (g oil/g waste)		Oil_w	$\left(\frac{2}{Oil_w\rho_{bw}}\right)^a$	V/R	R/100
Oil Content (g oil/g waste)		Oil_w	$\left(\frac{2}{Oil_w\rho_{bw}}\right)^b$	V/R	R/100
B (mg/kg)		B_w	$\left(\frac{5x1000}{B_w\rho_{bw}}\right)$	V/R	R/100
Cd (mg/kg)		Cd_w	$\left(\frac{1.5x1000}{Cd_w\rho_{bw}}\right)$	V/R	R/100
Cr (mg/kg)		Cr_w	$\left(\frac{100x1000}{Cr_w\rho_{bw}}\right)$	V/R	R/100
Cu (mg/kg)		Cu_w	$\left(\frac{200x1000}{Cu_w\rho_{bw}}\right)$	V/R	R/100

Continued ...

Table 9. Continued.

Parameter	Soil	Waste	Rate (m^3/ha)	Area (ha)	Depth (cm)
Pb (mg/kg)		Pb_w	$\left(\frac{100x1000}{Pb_w \rho_{bw}}\right)$	V/R	R/100
Ni (mg/kg)		Ni_w	$\left(\frac{25x1000}{Ni_w \rho_{bw}}\right)$	V/R	R/100
V (mg/kg)		V_w	$\left(\frac{100x1000}{V_w \rho_{bw}}\right)$	V/R	R/100
Zn (mg/kg)		Zn_w	$\left(\frac{300x1000}{Zn_w \rho_{bw}}\right)$	V/R	R/100
Wet Bulk Density (g/cm^3)		ρ_{bw}			
Water Content (g water/g waste)		θ_m			
Volume (m^3)		V			

a Calculation required at the 0.1 % oil limit.

b Calculation required at the 0.5 % oil limit

i. The total amounts (loadings) of an element (T_i) in a waste is calculated from the waste elemental concentration (C_{si}), wet bulk density (ρ_{bw}) and volume (V_s); Cl loadings require also the waste saturation (P_w). The loading for an element i is calculated as follows:

$$T_i(kg\ i) = C_i\left(\frac{mg\ i}{kg\ solid}\right)*\rho_{bw}\left(\frac{g\ solid}{cm^3\ wet}\right)*V_s(m^3\ wet)*\left(\frac{kg\ solid}{10^3\ g\ solid}\right)*\left(\frac{10^6\ cm^3\ wet}{m^3\ wet}\right)$$

ii. The soil:waste ratio (Ratio) of the mix can be estimated from the waste Cl and oil concentrations (C_i) and their regulatory limits (C_{li}) (assuming that the waste and soil have similar water contents (Θ_m) and wet bulk densities (ρ_{bw})) in the following manner:

$$\mathbf{Ratio}\ (oil\ based) = \frac{C_i\ (\%)}{C_{li}\ (\%)}\ ;\ \mathbf{Ratio}\ (Cl\ based) = \frac{C_i\left(\frac{mg\ i}{L}\right) * P_w\left(\frac{L}{kg}\right)}{C_{li}\left(\frac{mg\ i}{kg}\right)}$$

These calculations are summarized in Table 10.

8.2 LIQUID PHASE CALCULATIONS

The following equations are used to calculate liquid waste application rates (R_{li}), areas required (A_{li}) for application and the depth (thickness, D_{li}) of the waste layer that could be applied using the liquid phase volume (V_l), analyte concentrations (C_{li}) and its associated regulatory limit (L_i).

$$R_{li}\left(\frac{m^3}{ha}\right) = \left(\frac{L_i\left(\frac{kg\ i}{ha}\right)}{C_{li}\left(\frac{mg\ i}{L}\right)\ x\ 10^3\left(\frac{L}{m^3}\right)\ x\ 10^{-6}\left(\frac{kg\ i}{mg\ i}\right)}\right)$$

Table 10. Calculations for the Mix, Bury and Cover option for the disposal of a solid waste.

Parameter	Solids	Regulatory Limit (kg)	Total (kg)	Total/ Regulatory*
Cl (mg/L)	Cl_s	1600	$(Cl_s\ P_w\ \rho_{bw}\ V_s)/1000$	
Saturation (L/kg)	P_w			
B (mg/kg)	B_s	10	$(B_s\ \rho_{bw}\ V_s)/1000$	
Cd (mg/kg)	Cd_s	3	$(Cd_s\ \rho_{bw}\ V_s)/1000$	
Cr (mg/kg)	Cr_s	200	$(Cr_s\ \rho_{bw}\ V_s)/1000$	
Cu (mg/kg)	Cu_s	400	$(Cu_s\ \rho_{bw}\ V_s)/1000$	
Pb (mg/kg)	Pb_s	200	$(Pb_s\ \rho_{bw}\ V_s)/1000$	
Ni (mg/kg)	Ni_s	50	$(Ni_s\ \rho_{bw}\ V_s)/1000$	
V (mg/kg)	V_s	200	$(V_s\ \rho_{bw}\ V_s)/1000$	
Zn (mg/kg)	Zn_s	600	$(Zn_s\ \rho_{bw}\ V_s)/1000$	
Wet Bulk Density (g/cm^3)	ρ_{bw}			
Volume (m^3)	V_s			
		Regulatory Limit	Solid Conc.	Soil:Waste Ratio**
Oil Content (%)	O_s	0.1 (%)	O_s	$O_s/0.1$
Cl (mg/L)	Cl_s	2000 (mg/kg)	$(Cl_s\ P_w)$	$(Cl_s\ P_w)/2000$

* An analyte whose ratio (this column) is > 1 is considered limiting to MBC.

** Denotes the minimum appropriate soil:waste mix required if MBC is allowed.

$$\boldsymbol{A_{11}}\ (ha) = \left(\frac{\boldsymbol{V_1}\ (m^3)}{\boldsymbol{R_{11}} \left(\frac{m^3}{ha} \right)} \right)$$

$$\boldsymbol{D_{11}}\ (cm) = \boldsymbol{R_{11}} \left(\frac{m^3}{ha} \right) x\ 10^{-4} \left(\frac{ha}{m^2} \right) x\ 10^{2} \left(\frac{cm}{m} \right)$$

Liquid phase application rates based on pH, EC and SAR limits can be estimated as for the solid phase discussed previously with some modifications as described below. These application rates can be determined experimentally using the protocol for the solid phase except for adding the liquid waste to a leaching column instead of a plastic container. The application rate calculations will reflect the change from (kg/ha) of solid waste to (m^3/ha) of the liquid phase. It is important to reiterate that application of liquid drilling wastes should not result in any surface ponding or runoff.

Prediction of the resultant soil EC after application of liquid waste can be done using an approach recommended by Sposito (1989) and Shainberg and Shalhevet (1984) for irrigation water impacts on soils. Sposito (1989) and Shainberg and Shalhevet (1984) report that empirical relationships between the EC of the applied liquid phase (EC_w) and the EC of the soil after application (EC_s) are dependent on EC_w and the leaching fraction below the root zone (LF). The LF is defined as the ratio of water leached below a certain zone (e.g., root zone) to that applied (Sposito 1989):

$$LF = \frac{Volume\ of\ water\ leached\ below\ root\ zone}{Volume\ of\ water\ added}$$

The resultant soil EC_s after the liquid waste application is calculated as (Shainberg and Shalhevet 1984):

$$EC_s = 0.2\ EC_w \left(1 + \frac{1}{LF} \right)$$

LF values are typically from 0.15 to 0.2, which implies that for a soil limit of 4 dS/m, one is allowed to add liquid phase waste with EC_w of 2.6 to 3.3 dS/m.

Calculation of the resultant soil EC after an application of liquid waste at a rate R_l is dependent on the initial soil EC (EC_s) and saturation P (L/kg), waste EC (EC_w), and the limit EC (EC_c). The following equation can be used to estimate the application rate R_l (m^3/ha) allowed that will result in the EC of the soil-waste mix being equal to EC_c (it is assumed that the salts added with the liquid waste will remain initially in the surface soil layer):

$$\boldsymbol{R_{11}}\left(\frac{m^3}{ha}\right) = P\left(\frac{L}{kg}\right) * \left(\frac{EC_c - EC_s}{EC_w}\right) * 2000$$

The liquid waste application rate R_l (m^3/ha) based on SAR values is dependent on the soil and waste SAR and ion (Na, Ca, and Mg) values, and the SAR limit chosen for the soil-waste mix. The following equation can be used to estimate this application rate based on the soil SAR (SAR_s) and Na (Na_s) values, the waste SAR (SAR_w) and Na (Na_w) values, and the SAR limit (SAR_c) for the soil-waste mix. This equation does not take into account the probable precipitation of Ca ions in alkaline soil conditions and thus could underestimate the resultant SAR and hence overestimat the allowed application rate.

$$\boldsymbol{R_1}\left(\frac{m^3}{ha}\right)=\boldsymbol{P}\left(\frac{L}{kg}\right)*\left(\frac{(\boldsymbol{R_w}-2\boldsymbol{R_{Na}})+((2\boldsymbol{R_{Na}}-\boldsymbol{R_w})^2-4\boldsymbol{R_{Na}}^2(1-\boldsymbol{R_s}))^{0.5}}{2}\right)*2000$$

$$\text{Where } \boldsymbol{R_{Na}} = \left(\frac{\boldsymbol{Na_s}}{\boldsymbol{Na_w}}\right);\ \boldsymbol{R_w} = \left(\frac{\boldsymbol{SAR_c}}{\boldsymbol{SAR_w}}\right)^2;\ \text{and } \boldsymbol{R_s} = \left(\frac{\boldsymbol{SAR_c}}{\boldsymbol{SAR_s}}\right)^2$$

The above equations are summarized in Table 11. The use of Na application rates as surrogate limits for EC and SAR limits is as valid for the liquid phase as for the solid phase discussed in the previous section.

Table 11. Calculation of application rate, required area and depth of an applied liquid waste layer.

Parameter	Soil	Waste	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	EC_s	EC_w	$\left(\frac{EC_L-EC_s}{EC_w}\right)2000P_s,\ EC_L=4 \text{ or } (EC_s+1)$	V/R	R/100
Na (mg/L)	Na_s	Na_w	$\left(\frac{500x1000}{Na_w}\right)$	V/R	R/100
SAR	SAR_s	SAR_w	R_{SAR}[a]	V/R	R/100
Cl (mg/L)	Cl_s	Cl_w	$\left(\frac{800x1000}{Cl_w}\right)$	V/R	R/100
(NH_4+NO_3)-N (mg/L)		N_w	$\left(\frac{400x1000}{N_w}\right)$	V/R	R/100
Microtox©		Pass/ Fail			
Saturation (L/kg)	P_s				
Volume (m^3)		V			

[a] See text for the full equation.

8.3 COMBINED SOLID AND LIQUID PHASE CALCULATIONS

The following equations are used to calculate the potential application rates (R_{sli}) and areas required for application (A_{sli}) of both the liquid and solid phase wastes from each sump location.

The concentration of an element i (C_{sli}) in a combined drilling waste (mixed solids and liquids) is calculated from the concentration of i in the solid (C_{si}) and liquid (C_{li}) phases and the volumes of these two phases (V_s and V_l). The application rates (of the combined solid and liquid phases) based on EC and SAR values are calculated as the ratios of the waste volumes (liquid + solid) to the areas required, where the areas are calculated as the sum of the required areas for each of the waste liquid and solid phases when considered separately (see previous calculations).

$$C_{sli}\left(\frac{kg\ i}{m^3}\right) = \left(\frac{\left(C_s\left(\frac{kg\ i}{kg\ dry\ solids}\right) \times \rho_{bw}\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right) \times V_s\ (m^3\ wet\ solids)\right) + \left(C_{li}\left(\frac{mg\ i}{L}\right) \times 10^{-6}\left(\frac{kg\ i}{mg\ i}\right) \times 10^{-3}\left(\frac{L}{m^3}\right) \times V_l\ (m^3)\right)}{\left(V_s\ (m^3\ wet\ solids) + V_l\ (m^3)\right)}\right)$$

Application rates (R_{sli}) were calculated as follows:

$$R_{sli}\left(\frac{m^3}{ha}\right) = \left(\frac{L_i\left(\frac{kg\ i}{ha}\right)}{C_{sli}\left(\frac{kg\ i}{m^3}\right)}\right)$$

and areas (A_{sli}) as:

$$A_{sli}\ (ha) = \left(\frac{(V_s + V_l)\ (m^3)}{R_{sli}\left(\frac{m^3}{ha}\right)}\right)$$

8.4 EXAMPLES OF APPLICATION RATE CALCULATIONS

Calculation for the landspreading (application rate, area required and thickness of the applied layer) and the mix, bury and cover options will be illustrated for a KCl drilling waste (liquid and solid phases) to be landspread on a surface horizon of a Gray Luvisol. The results of the calculation for the KCl waste and for two others (an invert and a gel) are presented in Tables 12 to 20.

Table 12 provides the analytical data for a KCl solid phase waste and a soil that will be used as the waste receiving medium. The calculation for the application rate is done as follows:

8.4.1 Solid Phase Land Application Rates

i. The solid waste concentration of the analytes (B, Cd, Cr, Cu, Pb, Ni, V, and Zn) (Table 12) $e.g\left(\frac{mg\ Zn}{kg\ dry\ solids}\right)$ is converted to another unit $\left(\frac{kg\ Zn}{kg\ dry\ solids}\right)$ in the following manner:

$$C_{sZn} = \left(\frac{182.9\ mg\ Zn}{kg\ dry\ solids}\right) * 10^{-6}\left(\frac{kg\ Zn}{mg\ Zn}\right) = 1.83 * 10^{-4}\ \frac{kg\ Zn}{kg\ dry\ solids}$$

ii. Chloride concentrations in the saturated paste extracts $\left(\frac{26120\ mg\ Cl}{L}\right)$ (Table 12) are converted to $\left(\frac{kg\ Cl}{kg\ dry\ solids}\right)$ using the saturation content of the saturated paste (P) (Table 12) in the following manner:

$$C_{sCl} = \left(\frac{26120\ mg\ Cl}{L}\right) * 0.67\left(\frac{L}{kg\ dry\ solids}\right) * 10^{-6}\left(\frac{kg\ Cl}{mg\ Cl}\right) = 1.76 * 10^{-2}\ \frac{kg\ Cl}{kg\ dry\ solids}$$

iii. The solid waste wet bulk density (Table 9) $\rho_{bw}\left(\frac{0.79\ g\ dry\ solids}{cm^3\ wet\ solids}\right)$ is converted to $\left(\frac{kg\ dry\ solids}{m^3\ wet\ solids}\right)$ in the following manner:

Table 12. Calculation of application rate, required area and thickness of an applied KCl solid waste layer.

Parameter	Luvisolic Soil	KCl Solids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.56	61.9	69	43.48	1
Na (mg/L)	13.1	4822	196	15.31	2
SAR	0.5	38	485	6.19	5
Cl (mg/L)*	20.6	26120	58	51.72	1
Saturation (L/kg)	0.36	0.67			
Oil Content [a] (g oil/g waste)	0.00024 (0.024%)	0.0163 (1.63%)	155	19.35	2
Oil Content [b] (g oil/g waste)	0.00024 (0.024%)	0.0163 (1.63%)	775	3.87	8
B (mg/kg)		0.89	7,111	0.42	71
Cd (mg/kg)	0.13	0.10	18,987	0.16	190
Cr (mg/kg)	37.2	85.6	1,479	2.03	15
Cu (mg/kg)	14.0	26.9	9,411	0.32	94
Pb (mg/kg)	30.1	10.0	12,658	0.24	127
Ni (mg/kg)	17.0	34.3	923	3.25	9
V (mg/kg)	41.5	132	959	3.13	10
Zn (mg/kg)	43.6	183	2,075	1.45	21
Wet Bulk Density (g/cm^3)		0.79			
Water Content (g water/g waste)		0.89			
Volume (m^3)		3000			

* Cl is the most limiting analyte.

a Calculation for the 0.1 % oil rate limit.

b Calculation for the 0.5 % oil rate limit.

$$\rho_{bw} = \rho_{bw}\left(\frac{0.79 \; g \; dry \; solids}{cm^3 \; wet \; solids}\right) * 10^3 = 790 \; \frac{kg \; dry \; solids}{m^3 \; wet \; solids}$$

The wet bulk density is either measured from the weight of the dry waste and the volume of the wet waste, or calculated from the water content, oil content and an assumed solids density of 2.6 $\frac{g}{cm^3}$. The calculation for the wet bulk density (ρ_{bw}) from the above parameters (Table 12) is as follows:

$$\rho_{bw} = \left(\frac{1 + \theta_o}{\theta_m + \left(\frac{1}{\rho_s}\right) + \left(\frac{\theta_o}{0.9}\right)}\right) = \left(\frac{1 + 0.0163}{0.89 + \left(\frac{1}{2.6}\right) + \left(\frac{0.0163}{0.9}\right)}\right) = 0.79 \; \frac{g \; dry \; solids}{cm^3 \; wet \; solids}$$

iv. The solid waste application rate (R_s) based on the analytes (B, Cd, Cl, Cr, Cu, Pb, Ni, Na, V, and Zn) is calculated from the regulatory limit for each analyte (L) and the waste ρ_{bw} and analyte concentrations (C_s). As an example, the application rate for Zn (R_{sZn}) is calculated as follows:

$$R_{sZn} = \frac{L_{Zn}\left(\frac{300 \; kg \; Zn}{ha}\right)}{C_{sZn}\left(\frac{1.83*10^{-4} \; kg \; Zn}{kg \; dry \; solids}\right) * \rho_{bw}\left(\frac{790 \; kg \; dry \; solids}{m^3 \; wet \; solids}\right)} = 2076 \; \frac{m^3 \; wet \; solids}{ha}$$

v. The area required for waste application based on the above application rate is calculated for each analyte using the waste volume(Table 12), and is illustrated for the waste component Zn (A_{sZn}(ha)) as follows:

$$A_{sZn} \; (ha) = \frac{V_s \; (3000 \; m^3 \; wet \; solids)}{R_{sZn}\left(\frac{2076 \; m^3 \; wet \; solids}{ha}\right)} = 1.45 \; ha$$

vi. The thickness of the applied layer should also be calculated for each waste component, and is shown for Zn (D_{sZn} (cm wet waste)) as follows:

$$D_{sZn} = \frac{V_s\ (3000\ m^3\ wet\ solids)}{A_{sZn}\ (1.45\ ha)\ *\ 10^4 \left(\frac{m^2}{ha}\right)} * 10^2 \left(\frac{cm}{m}\right) = 21\ cm\ wet\ waste$$

or

$$D_{sZn} = R_{sZn} \left(\frac{2076\ m^3\ wet\ solids}{ha}\right) * 10^{-4} \left(\frac{ha}{m^2}\right) * 10^2 \left(\frac{cm}{m}\right) = 21\ cm\ wet\ waste$$

vii. The application rates of the KCl waste based on both EC and SAR values are dependent on the soil and waste EC and SAR values and their regulatory limits. Limits for EC (EC_c) and SAR (SAR_c) are 4 $\frac{dS}{m}$ and 10 respectively, or 1 unit higher than the soil values if the soil is already at or higher than these limits. We have shown in the previous section that EC_c and SAR_c should be corrected to fit the model used to describe waste and soil mixing, with the resulting EC_c and SAR_c being 2.22 $\frac{dS}{m}$ and 7.69 respectively. Therefore, X_{EC} and X_{SAR} can be calculated from the adjusted EC_c and SAR_c and the EC and SAR values of the waste and soil samples only.

$$X_{EC} = \frac{EC_c - EC_s}{EC_w - EC_s} = \frac{2.22 - 0.56}{61.9 - 0.56} = 0.027$$

and similarly for SAR, one obtains:

$$X_{SAR} = \frac{SAR_c - SAR_s}{SAR_w - SAR_s} = \frac{7.69 - 0.5}{38 - 0.5} = 0.192$$

The application rates (R_{EC} and R_{SAR}), areas required (A_{EC} and A_{SAR}) and waste layer thicknesses (D_{EC} and D_{SAR}) ca be calculated from the X values (for both EC and SAR limits) as follows:

$$\boldsymbol{R_{EC}} = \left(\frac{\boldsymbol{X_{EC}} \left(\frac{0.027 \text{ kg dry solids}}{\text{kg waste-soil mix}} \right) \left(\frac{2x10^6 \text{ kg waste-soil mix}}{\text{ha}} \right)}{\boldsymbol{\rho_{bw}} \left(\frac{790 \text{ kg dry solids}}{m^3 \text{ wet solids}} \right)} \right) = 69 \ \frac{m^3 \text{ wet solids}}{\text{ha}}$$

$$\boldsymbol{A_{EC}} = \left(\frac{\boldsymbol{V_s} \ (3000 \ m^3 \text{ wet solids})}{\boldsymbol{R_{EC}} \left(\frac{69 \ m^3 \text{ wet solids}}{\text{ha}} \right)} \right) = 43.48 \text{ ha}$$

$$\boldsymbol{D_{EC}} = \left(\frac{\boldsymbol{V_s} \ (3000 \ m^3 \text{ wet solids})}{\boldsymbol{A_{EC}} \ (44 \text{ ha}) x10^4 \ (\frac{m^2}{\text{ha}})} \right) x \ 10^2 \ (\frac{\text{cm}}{\text{m}}) = 0.69 \text{ cm wet solids}$$

$$\boldsymbol{R_{SAR}} = \left(\frac{\boldsymbol{X_{SAR}} \left(\frac{0.192 \text{ kg dry solids}}{\text{kg waste-soil mix}} \right) \left(\frac{2x10^6 \text{ kg waste-soil mix}}{\text{ha}} \right)}{\boldsymbol{\rho_{bw}} \left(\frac{790 \text{ kg dry solids}}{m^3 \text{ wet solids}} \right)} \right) = 485 \ \frac{m^3 \text{ wet solids}}{\text{ha}}$$

$$\boldsymbol{A_{SAR}} = \left(\frac{\boldsymbol{V_s} \ (3000 \ m^3 \text{ wet solids})}{\boldsymbol{R_{SAR}} \left(\frac{485 \ m^3 \text{ wet solids}}{\text{ha}} \right)} \right) = 6.19 \text{ ha}$$

$$\boldsymbol{D_{SAR}} = \left(\frac{\boldsymbol{V_s} \ (3000 \ m^3 \text{ wet solids})}{\boldsymbol{A_{SAR}} \ (6.2 \text{ ha}) x10^4 \ (\frac{m^2}{\text{ha}})} \right) x \ 10^2 \ (\frac{\text{cm}}{\text{m}}) = 4.8 \text{ cm wet solids}$$

8.4.2 Solid Phase Mix, Bury and Cover

The total amount (loading) of Zn (T_{Zn}) is calculated from the waste zinc concentration (C_{sZn}), wet bulk density (ρ_{bw}) and volume (V_s) as follows (Table 13):

$$\mathbf{T}_{Zn}(kg\ Zn) = C_{Zn}\left(\frac{183\ mg}{kg}\right)*\rho_{bw}\left(\frac{0.79\ g}{cm^3}\right)*V_s(1800\ m^3)*\left(\frac{kg}{10^3\ g}\right)*\left(\frac{10^6\ cm^3}{m^3}\right) = 260\ kg\ Zn$$

The soil:waste ratio (Ratio) of the mix is be estimated from the waste Cl (C_{Cl}) and oil concentrations (C_{Oil}) and their regulatory limits (2000 mg Cl/kg, and 0.1 % oil) assuming that the waste and soil have similar water contents (Θ_m) and wet bulk densities (ρ_{bw}) in the following manner (Table 13):

$$\mathbf{Ratio}(oil) = \frac{C_{Oil}(1.63\ \%)}{C_l oil(0.1\ \%)} = 16;\quad \mathbf{Ratio}(Cl) = \frac{C_{Cl}\left(\frac{26120\ mg\ Cl}{L}\right)*P_w\left(0.89\ \frac{L}{kg}\right)}{C_{Cl}\left(\frac{2000\ mg\ Cl}{kg}\right)} = 9$$

8.4.3 Liquid Phase Land Application Rates

The following equations will illustrate the use of the liquid data (Table 14) to calculate liquid waste application rates (R_{lCl}), areas required (A_{lCl}) for application and the depth (thickness, D_{lCl}) of a KCl waste layer (based on Cl data only) that could be applied using the liquid phase volume (V_l), analyte concentrations (C_{lCl}) and its associated regulatory limit (L_{Cl} = 800 kg/ha). Similar calculations should be performed on any other analyte required and the minimal application rate selected.

$$\mathbf{R}_{lCl} = \left(\frac{\mathbf{L}_{Cl}\left(\frac{800\ kg\ Cl}{ha}\right)}{\mathbf{C}_{lCl}\left(\frac{4932\ mg\ Cl}{L}\right) x\ 10^3\left(\frac{L}{m^3}\right) x\ 10^{-6}\left(\frac{kg\ i}{mg\ i}\right)}\right) = 162\ \frac{m^3}{ha}$$

Table 13. Calculations for the Mix, Bury and Cover option for the disposal of a KCl solid waste.

Parameter	KCl Solids	Regulatory Limit (kg)	Total (kg)	Total/ Regulatory
Cl (mg/L)*	26120	1600	24,885.57	15.6
Saturation (L/kg)	0.67			
B (mg/kg)	0.89	10	1.27	0.1
Cd (mg/kg)	0.10	3	0.14	0.0
Cr (mg/kg)	85.6	200	121.72	0.6
Cu (mg/kg)	26.9	400	38.25	0.1
Pb (mg/kg)	10.0	200	14.22	0.1
Ni (mg/kg)	34.3	50	48.77	1.0
V (mg/kg)	132	200	187.70	0.9
Zn (mg/kg)	183	600	260.23	0.4
Wet Bulk Density (g/cm^3)	0.79			
Volume (m^3)	1800			
		Regulatory Limit	KCl Solid Conc.	Soil:Waste Ratio
Oil Content (%)	1.63	0.1 (%)	1.63 %	16.3
Cl (mg/L)	26120	2000 (mg/kg)	17,500.40 mg/kg	8.8

* Cl limits the disposal of this waste through MBC.

Table 14. Calculation of application rate, required area and depth of an applied KCl liquid waste layer.

Parameter	Luvisolic Soil	KCl Liquids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.56	10.0	248	7.26	2
Na (mg/L)	13.1	2200	227	7.93	2
SAR*	0.5	58	77	23.38	1
Cl (mg/L)	20.6	4932	162	11.11	2
(NH_4+NO_3)-N (mg /L)		3.5	114,286	0.02	1,143
Saturation (L/kg)	0.36				
Volume (m^3)		1800			
Microtox©		Pass			

* SAR is the most limiting analyte.

$$\mathbf{A}_{1Cl} = \left(\frac{\mathbf{V}_1\ (1800\ m^3)}{\mathbf{R}_{1Cl} \left(162\ \frac{m^3}{ha}\right)} \right) = 11\ ha$$

$$\mathbf{D}_{1Cl} = \mathbf{A}_{1Cl} \left(162\ \frac{m^3}{ha}\right) x\ 10^{-4} \left(\frac{ha}{m^2}\right) x\ 10^{2} \left(\frac{cm}{m}\right) = 1.6\ cm$$

Calculation of the resultant soil EC after an application of liquid waste at a rate R_{1EC} is dependent on the initial soil EC (EC_s) and saturation P (L/kg), waste EC (EC_w), and the limit EC (EC_c). The following equation will be used to estimate the application rate R_{1EC} (m^3/ha) allowed that will result in the EC of the soil-waste mix being equal to EC_c (4 dS/m):

$$\mathbf{R}_{1EC} = P\left(\frac{L}{kg}\right) * \left(\frac{EC_c - EC_s}{EC_w}\right) * 2000 = \left(0.36\ \frac{L}{kg}\right) * \left(\frac{4 - 0.56}{10}\right) * 2000 = 248\ \frac{m^3}{ha}$$

As described previously, the liquid waste application rate R_{1SAR} (m^3/ha) based on SAR values is dependent on the soil and waste SAR and ion (Na, Ca, and Mg) values, and the SAR limit chosen for the soil-waste mix. The following equation will be used to estimate this application rate based on the soil SAR (SAR_s) and Na (Na_s) values, the waste SAR (SAR_w) and Na (Na_w) values, and the SAR limit (SAR_c) for the soil-waste mix. This equation does not take into account the probable precipitation of Ca ions in alkaline soil conditions and thus could underestimate the resultant SAR and hence overestimate the allowed application rate. The required area for application and the thickness of the applied layer can be calculated as described before.

$$\mathbf{R}_{Na} = \left(\frac{\mathbf{Na}_s}{\mathbf{Na}_w}\right) = \frac{13.09}{2200} = 0.00595;\ \mathbf{R}_w = \left(\frac{\mathbf{SAR}_c}{\mathbf{SAR}_w}\right)^2 = \left(\frac{10}{58}\right)^2 = 0.0297;\ and\ \mathbf{R}_s = \left(\frac{\mathbf{SAR}_c}{\mathbf{SAR}_s}\right)^2 = \left(\frac{10}{0.5}\right)^2 = 400$$

$$\boldsymbol{R_1}\left(\frac{m^3}{ha}\right)=\boldsymbol{P}\left(\frac{L}{kg}\right)*\left(\frac{(\boldsymbol{R_w}-2\boldsymbol{R_{Na}})+((2\boldsymbol{R_{Na}}-\boldsymbol{R_w})^2-4\boldsymbol{R_{Na}}^2(1-\boldsymbol{R_s}))^{0.5}}{2}\right)*2000$$

or

$$\boldsymbol{R_{1SAR}}=(0.36)*\left(\frac{(0.0297-2*0.00595)+((2*0.00595-0.0297)^2-4(0.00595^2)*(1-400))^{0.5}}{2}\right)*2000=77\ \frac{m^3}{ha}$$

Rates of application are to be determined for each regulated analyte or property for both the solid and liquid phase wastes. The analyte resulting in the minimal application rate is thus the limiting analyte and the one which should be used to calculate area and thickness relative to disposal of the waste.

8.5 INTERPRETATION OF THE CALCULATIONS

The results of the calculation undertaken in section 8.4 are presented for the solid and liquid phases of KCl, freshwater gel and diesel invert drilling wastes. This section will discuss the interpretation of these calculations in order to arrive at appropriate disposal rate(s) and if required, to suggest possible amelioration strategies; and to assess the suitability of mix, bury and cover as a disposal option.

Landspreading of the KCl drilling waste solid phase materials is limited by its Cl and EC values (Table 12) to rates of 58 and 69 m^3/ha respectively. Other waste parameters (e.g., SAR, metals) seem to be much less limiting and could become limiting only if the Cl and EC values are reduced by waste treatment. Treatment of the waste will be required if the recommended (appropriate) application rate and disposal area can not be met. Waste treatment to reduce EC and Cl values could include washing of the salts and ultimate disposal of the wash solution (containing salts) through deep well injection, and/or recovery of the salts (if economical). Reduction of the Cl and EC values will allow for an increased application rate and a corresponding reduction in the area required for disposal.

The use of mix, bury and cover for the disposal of this waste is evaluated in Table 13. The calculations show that the total Cl content of the waste is almost 16 times greater than the allowed limit, thereby eliminating mix, bury and cover as an option for disposal of this KCl waste.

Landspreading of the KCl liquid phase waste material is limited by its SAR value (Table 14). The other parameters that could be limiting are the Cl, Na and EC waste values. Disposal of this waste could proceed at the recommended rates or an alternate disposal method (e.g., deep well injection and/or salt recovery) could be attempted.

Disposal of the solid phase material for a freshwater gel drilling waste is limited by its SAR value followed by the oil and EC values, while other waste parameters (e.g., Cl and metals) seem to be much less limiting (Table 15). The limitation of disposal by oil content is due in large part to the low regulatory limit used (0.1% oil in the waste-soil mix), and should be viewed as an indicator of the need to use special measures (e.g., landfarming) to manage this waste. The landspreading rate limits due to the SAR and EC values could be increased by reducing the waste SAR value through appropriate treatment (e.g., addition of Ca containing materials such as gypsum and lime).

Mix, bury and cover for the freshwater gel waste is slightly limited by its Ni content (1.1 times the limit, Table 16). If a portion of this waste was disposed on site using mix, bury and cover, then the soil:waste ratio should be > 4 (Table 16) based on its oil content.

The freshwater gel liquid phase drilling waste is also limited by its SAR value (Table 17), while other waste parameter (e.g., EC, Cl and oil) are significantly less limiting. Treatment of the liquid phase with Ca containing materials (e.g., gypsum and lime) could reduce the SAR value and thus lead to an increased application rate. Care should be exercised in the treatments of both phases of this waste for high SAR values to ensure that the EC value does not increase significantly.

The data for the landspreading of an invert solid and liquid phase drilling waste are presented in Tables 18 to 20. Landspreading of the solid phase materials is limited by its oil and Cl contents, and EC value (Table 18). The limitation due to oil is an indication that this material should be treated as a special case and appropriate disposal methods used (e.g., landfarming). The appropriate rate of disposal based on oil should be one that leads to removal of the oil added in a short time period (years), and is usually between 1% (highly aromatic material) to 3% (crude oils and materials containing significant low molecular weight and/or saturated compounds) oil in the soil-waste mix.

Table 15. Calculation of application rate, required area and thickness of an applied Freshwater Gel solid waste layer.

Parameter	Luvisolic Soil	Freshwater Gel Solids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.56	6.2	841	3.81	8
Na (mg/L)	13.1	1100	1,249	2.56	12
SAR*	0.5	37	563	5.68	6
Cl (mg/L)	20.6	350	6,279	0.51	63
Saturation (L/kg)	0.36	0.52			
Oil Content[a] (g oil/g waste)	0.00024 (0.024%)	0.0043 (0.43%)	667	4.80	7
Oil Content[b] (g oil/g waste)	0.00024 (0.024%)	0.0043 (0.43%)	3,333	0.96	33
B (mg/kg)		0.93	7,680	0.42	77
Cd (mg/kg)	0.21	0.13	16,484	0.19	165
Cr (mg/kg)	37.2	53.8	2,655	1.21	27
Cu (mg/kg)	14.0	20.2	14,144	0.23	141
Pb (mg/kg)	10.3	30.1	4,746	0.67	47
Ni (mg/kg)	17.0	24.4	1,464	2.19	15
V (mg/kg)	41.5	75.2	1,900	1.68	19
Zn (mg/kg)	43.6	72.5	5,911	0.54	59
Wet Bulk Density (g/cm^3)		0.70			
Water Content (g water/g waste)		1.05			
Volume (m^3)		3200			

* SAR is the most limiting analyte.

a Calculation for the 0.1 % oil rate limit.

b Calculation for the 0.5 % oil rate limit.

Table 16. Calculations for the Mix, Bury and Cover option for the disposal of a Freshwater Gel solid waste.

Parameter	Freshwater Solids	Regulatory Limit (kg)	Total (kg)	Total/ Regulatory
Cl (mg/L)	350	1600	407.68	0.3
Saturation (L/kg)	0.52			
B (mg/kg)	0.93	10	2.08	0.2
Cd (mg/kg)	0.13	3	0.29	0.1
Cr (mg/kg)	53.8	200	120.51	0.6
Cu (mg/kg)	20.2	400	45.25	0.1
Pb (mg/kg)	10.3	200	23.07	0.1
Ni (mg/kg)*	24.4	50	54.66	1.1
V (mg/kg)	75.2	200	168.45	0.8
Zn (mg/kg)	72.5	600	162.40	0.3
Wet Bulk Density (g/cm^3)	0.70			
Volume (m^3)	3200			
		Regulatory Limit	Freshwater Solid Conc.	Soil:Waste Ratio
Oil Content (%)	0.43	0.1 (%)	0.43 %	4.3
Cl (mg/L)	350	2000 (mg/kg)	182.00 mg/kg	0.1

* Ni limits the disposal of this waste through MBC.

Table 17. Calculation of application rate, required area and depth of an applied Freshwater Gel liquid waste layer.

Parameter	Luvisolic Soil	Freshwater Gel Liquids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.56	1.17	2,117	0.40	21
Na (mg/L)	13.1	237	2,110	0.40	21
SAR*	0.5	13	987	0.85	10
Cl (mg/L)	20.6	90	8,889	0.09	89
(NH_4+NO_3)-N (mg/L)		1.5	266,667	0.00	2,667
Saturation (L/kg)	0.36				
Volume (m^3)		840			
Microtox©		Pass			

* SAR is the most limiting analyte.

Table 18. Calculation of application rate, required area and thickness of an applied Invert solid waste layer.

Parameter	Luvisolic Soil	Invert Solids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.20	29.5	104	3.46	1
Na (mg/L)	13.7	3128	245	1.47	2
SAR	0.4	12	945	0.38	9
Cl (mg/L)[*]	25.8	15345	80	4.50	1
Saturation (L/kg)	0.60	0.49			
oil content[a*] (g oil/g waste)	0.0004 (0.04%)	0.10 (10%)	15	24.00	0
oil content[b] (g oil/g waste)	0.0004 (0.04%)	0.10 (10%)	75	4.80	1
B (mg/kg)	0.07	0.52	7,230	0.05	72
Cd (mg/kg)	0.48	0.83	1,359	0.26	14
Cr (mg/kg)	40.5	64.7	1,162	0.31	12
Cu (mg/kg)	8.75	48.3	3,113	0.12	31
Pb (mg/kg)	14.2	63.1	1,192	0.30	12
Ni (mg/kg)	14.7	43.5	432	0.83	4
V (mg/kg)	49.3	93.9	801	0.45	8
Zn (mg/kg)	86.0	107	2,108	0.17	21
Wet Bulk Density (g/cm^3)		1.33			
Water Content (g water/g waste)		0.37			
Volume (m^3)		360			

[*] Oil (at the 0.1% limit) is the limiting analyte. If this waste is landfarmed, then Cl is the limiting analyte.

[a] Calculation for the 0.1 % oil rate limit.

[b] Calculation for the 0.5 % oil rate limit.

Other treatments of this waste could include the removal of Cl through washing as discussed for the KCl solid phase disposal. The metals and SAR values do not seem to be as limiting for disposal of this waste with Ni having the lowest application rate (5 times that of Cl).

The disposal of this invert waste by mix, bury and cover is severely limited both by its Cl (2 times the limit) and oil (requires a soil:waste ratio of 100) contents (Table 19).

The disposal of the invert drilling waste liquid phase is limited by its Cl content (Table 20). Treatment of this material is similar to its solid phase discussed above. The areas required are very small, due to the low liquid volume.

Table 19. Calculations for the Mix, Bury and Cover option for the disposal of an Invert solid waste.

Parameter	Invert Solids	Regulatory Limit (kg)	Total (kg)	Total/ Regulatory
Cl (mg/L)*	15345	1600	3,600.12	2.3
Saturation (L/kg)	0.49			
B (mg/kg)	0.52	10	0.25	0.0
Cd (mg/kg)	0.83	3	0.40	0.1
Cr (mg/kg)	64.7	200	30.98	0.2
Cu (mg/kg)	48.3	400	23.13	0.1
Pb (mg/kg)	63.1	200	30.21	0.2
Ni (mg/kg)	43.5	50	20.83	0.4
V (mg/kg)	93.9	200	44.96	0.2
Zn (mg/kg)	107	600	51.23	0.1
Wet Bulk Density (g/cm^3)	1.33			
Volume (m^3)	360			
		Regulatory Limit	Invert Solid Conc.	Soil:Waste Ratio
Oil Content (%)	10	0.1 (%)	10.00 (%)	100.0
Cl (mg/L)	15345	2000 (mg/kg)	7,519.05 (mg/kg)	3.8

* Cl limits the disposal of this waste through MBC.

Table 20. Calculation of application rate, required area and depth of an applied Invert liquid waste layer.

Parameter	Luvisolic Soil	Invert Liquids	Rate (m^3/ha)	Area (ha)	Depth (cm)
EC (dS/m)	0.2	3.72	1,226	0.04	12
Na (mg/L)	13.7	612	817	0.06	8
SAR	0.4	6	3411	0.01	34
Cl (mg/L)*	25.8	1931	414	0.12	4
(NH_4+NO_3)-N (mg/L)		4.5	88,889	0.00	889
Saturation (L/kg)	0.60				
Volume (m^3)		50			
Microtox©		Pass			

* Cl is the limiting analyte.

9. SITE MANAGEMENT FOLLOWING WASTE DISPOSAL

9.1 INTRODUCTION

After waste disposal has been completed, site management is generally minimized except for specific cases such as disposal of invert wastes. If the requirements outlined in the updated drilling waste disposal criteria and guidelines are met and the procedures described in this document are followed then the disposal of the waste should not affect reclamation certification. A well planned program of site management to avoid potential problems or address problems at an early stage is the best insurance for successful reclamation.

It is important to note that management practices required will ultimately be site specific even though there are general approaches that can be described for "agricultural" and "forest" land uses. Furthermore, management practice may vary somewhat based on the waste disposal procedure (mix, bury and cover, landspread, landfarm) utilized.

In general, site management will include the "root zone" portion of the reconstructed site with emphasis on the plant establishment zone or upper 30 cm.

9.2 PHYSICAL CHARACTERISTICS

The physical properties of the site are impacted by the disturbance and waste disposal regardless of the disposal procedure utilized. The degree of impact will vary depending upon the soil characteristics (texture, organic matter content, etc.), moisture content at the time of soil handling and type of equipment used.

One can expect an increase in soil density and reduction in soil porosity which can have an effect on moisture infiltration and other soil-plant relationships immediately after site preparation, however this impact should be short term. This impact is likely to occur at sites where material has been mixed, buried and covered, landspread in the subsoil or parent material or landspread on the surface. On the other hand, landspreading of drilling waste in the surface soil can have a positive impact on physical properties by increasing porosity and improving soil water characteristics (Macyk et al. 1992a).

Degraded physical characteristics can be mitigated by appropriate "cultivation" techniques where feasible, by plant establishment, and by natural processes such as frost action. It will be easier to improve the physical characteristics of a cultivated or annually cropped site than a pasture or forested site.

9.3 CHEMICAL CHARACTERISTICS

The chemical properties of the site will also be impacted by the disturbance and waste disposal and degree of impact will vary more on the basis of disposal procedure used than would be the case for physical properties.

Mix, bury and cover should result in minimal change in the chemical characteristics of the "root zone" material in that at least 1 m of "clean" subsoil is replaced on the waste/soil mixture and surface soil or topsoil replaced on the surface. With the exception of slight changes in pH and organic matter content due to mixing during salvage and replacement, chemical properties should not change significantly. The soil/waste mixture characteristics will have changed, however there is little or nothing that can be done to manage this subsurface material.

Landspreading in the subsoil or below the topsoil layer will have some impact on the chemical properties of this layer. The extent of the impact will depend upon the characteristics of the waste and the receiving soil and the method of waste incorporation used. Again, the criteria outlined for landspreading protect against significant negative impact. Where significant impacts do occur soil amendments may be required to ameliorate the condition.

Landspreading in the surface soil can result in both positive and negative impacts again depending on the characteristics of the receiving soil and the waste applied and the method of waste incorporation used. Generally, drilling waste addition will result in an increase in pH regardless of waste type. Increases in EC, SAR, and chloride content can occur as a result of adding salt-based drilling wastes and some gel systems. Increased salt levels and hydrocarbon content are an obvious result of the addition of diesel invert wastes.

Addition of drilling waste can supply macronutrients and micronutrients which are beneficial to plant growth and are at least partially responsible for the increased yields that can occur with drilling waste amended soils (Macyk et al. 1992a).

9.3.1 Fertilization

Fertilization will usually improve plant establishment and growth for any soil medium remaining after wellsite cleanup and waste disposal regardless of the disposal procedure utilized. Fertilizer addition is critical to assist microbial decomposition of hydrocarbons where required. For wastes containing hydrocarbons, a fertilizer high in nitrogen is needed because a large amount of nitrogen is consumed as the microbial population increases.

In the native prairie area of Alberta fertilization may not be an acceptable practice, therefore the local regulatory field staff should be consulted prior to any fertilizer application.

For diesel invert wastes, fertilizing and tillage should be conducted for a minimum of one or two growing seasons before proceeding with the next stage in the reclamation process. The actual time required for any given site will be dependent upon the initial oil and grease content in the soil/waste mixture and the climatic (precipitation, temperature) characteristics of the site.

Large fertilizer applications should be divided into periodic smaller applications to make more efficient use of the nutrients added (minimize losses) and to prevent potential toxicities to plants and soil organisms and contamination of surface water and groundwater.

9.4 MONITORING

Monitoring is an important part of site management and the overall reclamation process. Some locations may require very little or no monitoring whereas others may require significantly more depending upon site conditions, waste type, etc. Some level of monitoring should be done at every site until the site has been certified by the appropriate regulatory agency.

Undisturbed areas adjacent to the wellsite or disturbed area should provide the basis for comparison with soil properties within the disturbed area. Comparing soil characteristics onsite with soils in adjacent undisturbed areas indicates whether the wellsite or disturbed area has been reclaimed adequately. If a problem is identified and corrective action is taken then further testing is needed to determine whether the problem has ultimately been rectified.

Sampling and analysis must be done properly to allow meaningful interpretation. Also, it is important to ensure that monitoring is comprehensive enough to identify the fate of the wastes. Surface samples are easy to collect and will indicate the state of the seedbed, but they give no indication of whether subsoils or groundwater are being affected -- this can only be determined by thorough deeper sampling.

10. MEASUREMENT OF RECLAMATION SUCCESS

The objective or goal of reclamation of disturbed lands in Alberta is defined in terms of "equivalent land capability" under the Alberta Environmental Protection and Enhancement Act (Government of the Province of Alberta 1992). Equivalent land capability is defined as "the ability of the land to support various land uses after reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the ability support individual land uses will not necessarily be identical after reclamation".

A number of systems have been developed to measure land/soil capability in Alberta and Canada (Alberta Soils Advisory Committee 1987b; Brocke 1977; Canada Land Inventory 1965). Systems for measuring reconstructed soil capability have also been developed and are based largely on the original CLI Land Capability System (Leskiw and Lapointe 1992, Macyk 1987).

Evaluation of the degree of reclamation success based on soil parameters can also be done based on soil quality criteria that have been established and used in Alberta (Alberta Soils Advisory Committee 1987a). These criteria are based on the generic materials (soils) handling procedures common to the Plains, Northern Forest and Eastern Slopes Regions of Alberta. The specific soil properties that are included in the evaluation are:

1. pH
2. Salinity (EC)
3. Sodicity (SAR)
4. Saturation %
5. Stoniness class
6. Texture
7. Moist consistency
8. Organic carbon (%)
9. $CaCO_3$ equivalent (%)

Several of the above mentioned parameters and respective limits are included in the criteria defined for landspreading of drilling wastes.

The Land Conservation and Reclamation Council of Alberta Environmental Protection has completed the development of a draft guideline package to clarify the requirements for obtaining reclamation certificates (Alberta Environmental Protection 1992). This package which is currently being reviewed, contains reclamation criteria for wellsites and associated facilities. These criteria make use of concepts from the above documents.

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12. GLOSSARY

Acid Neutralizing Capacity:	The amount of strong acid required to reduce the pH of a system (i.e. soils) to a reference pH value. In agricultural soils, a reference pH of 5 is considered appropriate. In forest soils, a reference pH of 3 is probably more suitable.
Acid Soil:	A soil whose root zone is acidic, having a pH of less than 6.6 or 7.0, i.e., less than that of a neutral soil. There is preponderance of hydrogen over hydroxyl ions in the soil solution.
Alkaline Soil:	A soil having a pH greater than 7.0.
Alkalinity (soil):	The degree of intensity of alkalinity of a soil expressed by a value greater than 7.0 on the pH scale.
Aquifer:	A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.
Base Saturation Percentage:	The extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen and aluminum. It is expressed as a percentage of the total cation exchange capacity.
Bedrock:	The solid rock that underlies soil and the regolith or that is exposed at the surface.
Bulk Density:	The mass of dry soil per unit bulk volume. The bulk volume is determined before the soil is dried to constant weight at 105°C.
Burial:	With respect to the disposal of drilling wastes, the complete covering of the drilling solids with uncontaminated material. There are four methods of burial, ranging from minimal disturbance to total containment of the waste material: capping; mix, bury and cover; trenching; and encapsulation.
Cation Exchange Capacity:	Exchange capacity is the ability of a substance to have ion exchange, to exchange adsorbed ions for ions in solution. Cation exchange capacity refers to this ability with respect to cations. It is expressed in milliequivalents per 100 g of soil (or other adsorbing material).
Clay (soils):	1. A mineral soil separate consisting of particles less than 0.002 mm in diameter; 2. a soil textural class; 3. (engineering) a fine grained soil that has a high plasticity index in return relation to the liquid limit.
Coarse Fragments:	Rock or mineral particles greater than 2.0 mm in diameter.
Composite:	A sample consisting of a number of thoroughly mixed samples in which each contributes equally to the composite. Composite samples provide only an estimate of the mean of the population from which the samples forming the composite are drawn.

Contaminant:	Any foreign compound which is not naturally present and which is introduced into the environment by man.
Contamination:	The addition of any substance or property preventing the use or reducing the usability of the receiving medium.
D'arcy's Law:	A derived formula for the flow of fluids. It assumes that the flow is laminar and that inertia can be neglected.
Diversion Ditch:	A channel constructed across a slope to intercept surface runoff, changing the course of all or part of a stream or runoff, thereby reducing sediment problems.
Drainage:	The manner in which the waters of an area pass or flow off by surface streams or subsurface conduits. The removal of excess water from soil by downward flow.
Drilling Mud:	A heavy suspension, usually in water but sometimes in oil, used in rotary drilling, consisting of various substances in a finely divided state (commonly bentonitic clays and chemical additives such as barite), introduced continuously down the drill pipe under hydrostatic pressure, out through openings in the drill bit, and back up in the annular space between the pipe and the walls of the hole and to a surface pit where it is purified and reintroduced into the pipe. It is used to lubricate and cool the bit, to carry the cuttings up from the bottom, and to prevent blowouts and cave-ins.
Drilling Waste Fluids:	A heterogeneous mixture of water, drilling muds, borehole cuttings, additives and various other wastes that are specifically related to the actual drilling activity.
Drilling Waste Solids:	The bottom layer of sump material, composed of drill cuttings, flocculated bentonite, weighting materials and other additives, with minimal or no outflow of liquid.
Encapsulation:	(A method of drilling waste disposal). Total containment of the decanted sump contents (liquids removed) by using low permeability liners, capped by one metre of compacted material. The encapsulated area is then covered with subsoil and topsoil.
Environment:	The whole complex of climatic, edaphic, and biotic factors that act upon an organism or an ecological community, and ultimately determine its form and survival.
Equivalent Land Capability:	The ability of the land to support various land uses after reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the ability to support individual land uses will not necessarily be identical after reclamation.
Exchangeable Cations:	Cations that are adsorbed on the exchange complex and which are capable of exchange with other cations in solution.

Exchangeable Sodium Percentage (ESP):	The extent to which the adsorption complex of a soil (or other adsorbing material) is occupied by sodium. It is expressed as: ESP = (exchangeable sodium/cation exchange capacity) 100 where exchangeable sodium and cation exchange capacity are expressed in meq/100 g soil.
Fixation:	A process which chemically and/or physically changes a material such that its final leaching characteristics are more acceptable for disposal.
Gravel:	Rock fragments 2 mm to 7.5 cm in diameter.
Groundwater:	Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.
Hydraulic Conductivity:	The relative ability of a soil, rock or sediment to transmit fluid (water) through it. It is a function of the medium and the fluid. Figure 9 lists ranges of hydraulic conductivity values for various materials.
Hydraulic Gradient:	In an aquifer, the rate of change of pressure head (h) per unit of distance of flow at a given point and in a given direction.
Hydrogeology:	The science that deals with subsurface waters and related geologic aspects of surface waters.
Hydrology:	The science that deals with continental water, its properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere, from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the ocean.
Impermeability:	The condition of a rock, sediment, or soil that renders it incapable of transmitting fluids under pressure.
Impervious:	Resistant to penetration by fluids or roots.
Infiltration:	The downward entry of water into the soil.
Land Classification:	The arrangement of land units into various categories based on the properties of the land or its suitability for some particular purpose.
Landfarming:	A waste treatment/disposal method whereby a single or multiple applications of biodegradable wastes are made on a dedicated parcel of land which is managed in a manner which allows the soil system to degrade, transform and assimilate the waste constituents.
Landscape:	All the natural features such as fields, hills, forests, and water that distinguish one part of the Earth's surface from another part. Usually it is the portion of land or territory that the eye can see in a single view, including all its natural characteristics.

Landspreading:	A disposal method whereby the waste is spread over a predetermined land area based on an acceptable loading rate. Landspreading is usually done for wastes containing elevated levels of heavy metals and/or salts, and involves a single application.
Land Treatment:	(A method of drilling waste disposal). This is also termed landfarming, and is the continuous treatment of wastes on a dedicated land area which is managed in a manner that optimizes the degradation, transformation and assimilation of the waste constituents into the soil system. Soil, surface water and groundwater quality must not be degraded as a result of use of this method.
Leachate:	A solution obtained by leaching: e.g., water that has percolated through soil containing soluble substances and contains certain amounts of these substances in solution.
Leaching:	The removal from soil of materials in solution.
Liquids:	Components of drilling sump contents that contain less than 5% total suspended solids (TSS).
Microtox® Test:	Toxicity test using bacteria as test organisms. During the test, the production of light by the organisms reflects their state of health in response to the sample constituents.
Mineralogy (soil):	The subspecialization of soil science dealing with the homogeneous inorganic materials found in the earth's crust to the depth of weathering or sedimentation.
Mix, Bury and Cover:	A method whereby sump solids are stabilized and diluted by mixing with subsoil. The waste materials must be mixed at least 1:1 by volume with the subsoil. The stable waste is then placed into the original sump, or other sumps, and is covered with at least one metre of clean subsoil, and then the original topsoil.
Mobility:	The ability of a substance to move from one point to another.
Muck:	An organic soil consisting of highly decomposed materials.
Parent Material:	The unconsolidated, and more or less chemically weathered mineral or organic matter from which the solum of a soil has developed by pedogenic processes.
Particle Size Distribution:	The amount of the various soil separates (sand, silt, and clay) in a soil sample, usually expressed as weight percentages.
Peat:	Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter.
Percolation:	Downward movement of water through soils.

Permeability:	The property or capacity of a porous rock, sediment or soil for transmitting a fluid without impairment of the structure of the medium.
pH:	The degree of acidity or alkalinity of a substance as measured by the concentration of hydrogen ions. On this scale, pH of one is a strong acid, pH of 14 is a strong alkali; pH of seven is the point of neutrality.
Porosity:	The volume percentage of the total bulk not occupied by solid particles. It can be expressed numerically as: $n = F(V_v, V_T)$ where V_v is the volume of the voids and V_T the volume of the soil or rock.
Sand:	A soil particle between 0.05 and 2.0 mm in diameter.
Silt:	Small mineral soil grains, the particles of which range in diameter from 0.002 to 0.05 mm.
Sodic Soil:	A soil containing sufficient sodium to interfere with the growth of most crop plants. A soil having an exchangeable sodium percentage of 15 or more.
Sodium Adsorption Ratio:	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil. It is highly correlated to ESP and as such is used as its surrogate.
Soil:	The naturally occurring, unconsolidated mineral or organic material at least 10 cm thick that occurs at the Earth's surface and is capable of supporting plant growth.
Soil Horizon:	A layer of soil or soil material approximately parallel to the land surface; it differs from adjacent genetically related layers in properties such as colour, structure, texture, consistence, and chemical, biological, and mineralogical composition.
Soil Series:	Soil series are subdivisions of soil families based upon relatively detailed properties of the pedon within the depth of the control section. Pedons classified as a given soil series have a similar number and arrangement of horizons whose color, texture, structure, consistence, thickness, reaction or some combinations of these properties are within a defined range.
Soil Survey:	The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of the field examination.
Soil Texture:	The relative proportions of the various soil separates (clay, sand and silt) in a soil. Texture classes used in the manual are defined in Table 14 and shown in Figure 10.

Solidification:	A process which chemically and/or physically changes a fluid into a solid.
Solids:	Components of drilling sump contents that contain equal to or greater than 5% total suspended solids (TSS).
Spudding In:	1. The beginning of actual drilling operations on a well or borehole. 2. The first abrasion of the soil by the drill, or the first entrance of the drill into the ground. 3. The preliminary boring of a well through earth material down to rock or other solid substrata.
Subsoil:	1. A synonym of B horizon in a soil profile having distinct horizons. 2. The soil below the topsoil.
Sump (drill):	A surface excavation or diked area to hold water, drilling mud, sludge, and discharged matter from drilling, such as a pit in which water (mixed with mud, if necessary) can be stored for circulation through a drill hole or a pit in which the cuttings from drilling are received, trapped, and separated from the drilling mud.
Surficial Deposits:	Unconsolidated and residual, alluvial, or glacial deposits lying on bedrock or occurring on or near the Earth's surface; it is generally unstratified and represents the most recent of geologic deposits.
Surficial Geology:	Geology of surficial deposits, including soils; the term is sometimes applied to the study of bedrock at or near the Earth's surface.
Topography:	1. The general configuration of a land surface of any part of the Earth's surface, including its relief and the position of its natural and man-made features. 2. The natural or physical surface features of a region, considered collectively as to form; the features revealed by the contour lines of a map.
Topsoil:	1. The layer of soil moved in cultivation. 2. The A horizon. 3. The Ah horizon.
Trafficability:	The quality or suitability of the soil or terrain to permit passage.
Water Table:	The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

Table 21. Texture Classes (from Glossary of Terms in Soil Science, 1972).

Texture Class	Definition	Abbreviation
Clay	Soil material containing 40% or more clay, less than 45% sand and less than 40% silt.	C
Clay Loam	Soil material containing 27-40% clay and 20-45% sand.	CL
Heavy Clay	Soil material containing more than 60% clay.	HC
Loam	Soil material containing 7-27% clay, 28-50% silt and less than 52% sand.	L
Loamy Fine Sand	50% or more fine sand or less than 25% very coarse, coarse, and medium sand and less than 50% very fine sand.	LFS
Loamy Sand	Soil material containing at the upper limit 85-90% sand, and the percentage of silt plus 1.5 times the percentage of clay not less than 15; at the lower limit containing not less than 70-85% sand, and the percentage of silt plus twice the percentage of clay not exceeding 30.	LS
Sand	Soil material containing 85% or more sand; the percentage of silt plus 1.5 times the percentage of clay not exceeding 15.	S
Sandy Clay Loam	Soil material containing 20-35% clay, less than 28% silt and 45% or more sand.	SCL
Sandy Clay	Soil material containing 35% or more clay and 45 or more sand.	SC
Sandy Loam	Soil material containing either 20% or less clay, and the percentage of silt plus twice the percentage of clay exceeding 30, and 52% or more sand; or less than 7% clay, less than 50% silt, and between 43% and 52% sand.	SL
Silt Loam	Soil material containing 50% or more silt and 12-27% clay, or 50-80% silt and less than 12% clay.	SiL
Silt	Silt material containing 80% or more silt and less than 12% clay.	Si
Silty Clay Loam	Soil material containing 27-40% clay and less than 20% sand.	SiCL
Silty Clay	Soil material containing 40% or more clay and 40% or more silt.	SiC

APPENDIX I: ANALYTICAL METHODS

- Liquid Phase Analytical Methods
- Solid Phase Analytical Methods
- Soil Analytical Methods
- References

LIQUID PHASE ANALYTICAL METHODS

SAMPLE PREPARATION

Pass the sample through a 0.45 µm filter and use for the following analyses (except for TSS where the whole sample is used, and Microtox® Bioassay where centrifuging is required).

Analytical Parameter and Reporting Units	Procedure	Reference
pH	Combination electrode and pH meter.	Method 4500 h in APHA (1992).
Specific conductance (dS/m)	Conductivity cell and conductance meter.	Method 2510 in APHA (1992).
Ca, Mg, Na, K (mg/l)	All ions can be measured by Inductively Coupled Atomic Emission Spectroscopy (ICP-AES) or Atomic Absorbtion (AA). Flame Photometry can be used for Na and K only.	Methods 3500 C for ICP-AES, 3500 B for AA, or 3500 D for flame photometry in APHA (1992).
Chloride (mg/l)	Colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Methods 4500-CL E (colorimetric) or 4500-CL F (IC) in APHA (1992).
NO_3 (mg/l)	Colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Methods 4500-NO_3 E or F in APHA (1992).
SO_4 (mg/l)	Colorimetric measurement using Flow Injection (FIA), or Ion Chromatography (IC).	Method 4500-SO_4 F (colorimetric) or 4500 -SO_4B in APHA (1992).
NH_4 (mg/l)	Manual colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Method 4500-NH_4 B followed by 4500-NH_4 D, or 4500-NH_4 H in APHA (1992).
Sodium Adsorption Ratio (SAR)	Calculated from soluble ions (Ca, Mg, and Na).	Method 3.26 in McKeague 1978.
Total Suspended Solids (TSS) (mg/l)	Filter though a porcelain crucible containing preignited glass fibre filter (1.2 µm). The residue retained by the glass fibre filter is dried to a constant weight at 105°C for one hour.	Method 2540 D in APHA (1992).
Microtox® Bioassay	Measure EC20 and EC50 at both 5 and 15 minutes.	ERCB (1992)

SOLID PHASE ANALYTICAL METHODS

SAMPLE PREPARATION

Air dry (less than or equal to 2% water content) and grind in a manner which will not break down individual particles. Collect a representative portion passing a 2 mm stainless steel sieve.

CHARACTERIZATION

Analytical Parameter and Reporting Units	Procedure	Reference
Water content (θ_m) (grams water + grams dry solids)	Air dry	Method 2.411 in McKeague (1978) except air dry the sample instead of drying at 105°C.
pH (I) pH (II)	Water paste 2:1 slurry of 0.01 M $CaCl_2$. Use combination electrode and pH meter.	Methods 3.14 and 3.11 in McKeague (1978).
Saturated paste and paste solution	Saturated extract is prepared by USDA Soil Salinity lab method, filtered through 0.45 µm filter and the extracts used for analyses described below.	Method 3.21 in McKeague (1978).
Percent saturation (%)	Oven dry a soil paste sample.	Method 3.21 in McKeague (1978).
Electrical conductivity of saturated paste extract (dS/m)	Conductivity cell and conductance meter	Method 2510 in APHA (1992)
Chloride in saturated paste extract (mg/L)	Colorimetric measurement using Flow Injection (FIA), Autoanalyzer® or Ion Chromatography (IC)	Methods 4500-CL E (colorimetric) or 4500-CL F (IC) in APHA (1992)
Ca, Mg, Na, K in saturated paste extract (mg/L)	All ions can be measured by Inductively Coupled Atomic Emission Spectroscopy (ICP-AES) or Atomic Absorption (AA). Flame Photometry can be used for Na and K only.	Methods 3500 C for ICP-AES, 3500 B for AA, or 3500 D for flame photometry in APHA (1992).
SAR of saturated paste extract	Calculated from soluble ions (Ca, Mg, and Na)	Method 3.26 in McKeague (1978).
Hot water soluble Boron (mg/kg)	ICP-AES or curcumin colour	Methods 4500-B D or 4500-B B in APHA (1992).

continued ...

(Concluded). SOLID PHASE ANALYTICAL METHODS

SAMPLE PREPARATION

Air dry (less than or equal to 2% water content) and grind in a manner which will not break down individual particles. Collect a representative portion passing a 2 mm stainless steel sieve.

CHARACTERIZATION

Analytical Parameter and Reporting Units	Procedure	Reference
Corrected wet bulk density (g/cm^3)	Calculated from the (weight of of dry solids) + (volume of wet waste). or Estimated from the water content (θ_m) and density of solids as follows: $1/(\theta_m + 0.38)$ (This assumes that oil content of waste is negligible)	Abboud, 1993
Metals analysis (Cr, V, Cd, Cu, Pb, Zn, Ni) (mg/kg)	Hot acid (HNO_3-HF) digestion in closed teflon vessels under microwave heating followed by ICP-AES or AA measurements.	Digestion as in Abboud (1991) and metals using methods 3500 C (ICP) or B (AA) in APHA (1992).
Oil content (%)	Measured gravimetrically by Soxhlet Extraction with methylene chloride*.	McGill & Rowell 1977.
Texture	Hand method	Method 4.8 in McKeague (1978).

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* The determination of oil content using this method may provide false positive values, due to the presence of substances such as tannins and humic or fulvic acids. Corrections for these substances should be made (Refer to Method 5510-C in APHA (1992)).

SOIL ANALYTICAL METHODS

SAMPLE PREPARATION

Air dry (less than or equal to 2% water content) and grind in a manner which will not break down individual particles. Collect a representative portion passing a 2 mm stainless steel sieve.

CHARACTERIZATION

Analytical Parameter and Reporting Units	Procedure	Reference
pH (I) pH (II)	Water paste (2.2 extract) 2:1 slurry of 0.01 M $CaCl_2$. Use combination electrode and pH meter.	Methods 3.14 and 3.11 in McKeague (1978).
(a) Saturated paste and paste extract solution	Saturated extract is prepared by USDA Soil Salinity lab method, filtered through 0.45 µm filter and the extracts used for analyses 2.1, 2.3 to 2.6.	Method 3.21 in McKeague (1978).
(b) Percent saturation (%)	Oven dry a soil paste sample.	Method 3.21 in McKeague (1978).
Electrical conductivity of saturated paste extract (dS/m)	Conductivity cell and conductance meter.	Method 2510 in APHA (1992).
Ca, Mg, Na, K in saturated paste extract (mg/L)	All ions can be measured by Inductively Coupled Atomic Emission Spectroscopy (ICP-AES) or Atomic Absorption (AA). Flame Photometry can be used for Na and K only.	Methods 3500 C for ICP-AES, 3500 B for AA, or 3500 D for flame photometry in APHA (1992).
SAR of saturated paste extract	Calculated from soluble ions (Ca, Mg, and Na)	Method 3.26 in McKeague (1978).
Chlorides in saturated paste extract (mg/L)	Colorimetric measurement using Flow Injection (FIA). Autoanalyzer®, or Ion Chromatography (IC)	Methods 4500-CL E (colorimetric) or 4500-CL in APHA (1992).

LIQUID PHASE ANALYTICAL METHODS

SAMPLE PREPARATION

Pass the sample through a 0.45 µm filter and use for the following analyses (except for TSS where the whole sample is used, and Microtox® Bioassay where centrifuging is required).

CHARACTERIZATION

Analytical Parameter and Reporting Units	Procedure	Reference
pH	Combination electrode and pH meter.	Method 4500 h in APHA (1992).
Specific conductance (dS/m)	Conductivity cell and conductance meter.	Method 2510 in APHA (1992).
Ca, Mg, Na, K (mg/l)	All ions can be measured by Inductively Coupled Atomic Emission Spectroscopy (ICP-AES) or Atomic Absorbtion (AA). Flame Photometry can be used for Na and K only.	Methods 3500 C for ICP-AES, 3500 B for AA, or 3500 D for flame photometry in APHA (1992).
Chloride (mg/l)	Colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Methods 4500-CL E (colorimetric) or 4500-CL F (IC) in APHA (1992).
NO_3 (mg/l)	Colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Methods 4500-NO_3E or F in APHA (1992).
SO_4 (mg/l)	Colorimetric measurement using Flow Injection (FIA), or Ion Chromatography (IC).	Method 4500-SO_4 F (colorimetric) or 4500-SO_4B in APHA (1992).
NH_4 (mg/l)	Manual colorimetric measurement using Flow Injection (FIA), Autoanalyzer®, or Ion Chromatography (IC).	Method 4500-NH_4 B followed by 4500-NH_4 D, or 4500-NH_4 H in APHA (1992).
Sodium Adsorption Ratio (SAR)	Calculated from soluble ions (Ca, Mg, and Na).	Method 3.26 in McKeague 1978.
Total Suspended Solids (TSS) (mg/l)	Filter through a porcelain crucible containing preignited glass fibre filter (1.2 µm). The residue retained by the glass fibre filter is dried to a constant weight at 105°C for one hour.	Method 2540 D in APHA (1992).
Microtox® bioassay	Measure EC20 and EC50 at both 5 and 15 minutes.	ERCB (1992)

REFERENCES

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3. ERCB, 1992. ERCB Microtox® bioassay method. ERCB, Calgary, Alberta.

4. McGill, W.B. and M.J. Rowell, 1977. Extraction of oil from soils. Chapter 4. In: "The Reclamation of Agricultural Soils After Oil Spills, Part I: Research", edited by J.A. Toogood. AIP Publication M-77-11, University of Alberta, Edmonton.

5. McKeague, J.A. (Ed.), 1978. Manual on soil sampling and methods of analysis. 2nd Edition. Prepared by the Subcommittee on Methods of Analysis of the Canada Soil Survey Committee, Canadian Society of Soil Science. Ottawa. 212 pp.

APPENDIX II. ANALYTICAL PARAMETERS THAT PROVIDE A DETAILED CHARACTERIZATION OF DRILLING WASTES.

Appendix II. Analytical Parameters that Provide a Detailed Characterization of Drilling Wastes.

LIQUID	SOLID
pH	Water content
Electrical Conductivity (EC)	pH (I)
Calcium (Ca) Magnesium (Mg) Sodium (Na) Potassium (K) Chloride (Cl) Sulfate (SO_4) Carbonate (CO_3) Bicarbonate (HCO_3) Nitrate (NO_3) Ammonium (NH_4)	Saturated paste and paste extract pH Electrical Conductivity (EC) Calcium (Ca) Magnesium (Mg) Sodium (Na) Potassium (K) Chloride (Cl) Sulfate (SO_4) Nitrate (NO_3) Ammonium (NH_4)
Total dissolved solids (TDS) Sodium Adsorption Ratio (SAR) (calculated)	Sodium Adsorption Ratio (SAR) (calculated) Elemental Constituents (Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn, Mn, Li, Sr, Ba, S, Mo, Ni, Se, As, Co, Si)
Total suspended solids (TSS)	
Total organic carbon (TOC)	Total carbon
Elemental Constituents (Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn, Mn, Li, Sr, Ba, S, Mo, Ni, Se, As, Co, Si)	$CaCO_3$ equivalent
Microtox® bioassay	Particle size
Trout bioassay	Cation exchange capacity, exchangeable cations, Base Saturation percentage (calculated)
	Total elemental analysis
	Mineralogy
	Plant available elements
	Oil content Oil fractionation (acid, base, neutral fractions) - followed by GC-MS
	Microtox® bioassay Trout bioassay

RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes. Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-2: Alberta's Reclamation Research Program - 1979. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,190,006 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

4. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. No longer available.**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

5. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

6. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

7. **RRTAC 81-1: The Alberta Government's Reclamation Research Program - 1980. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,455,680 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

8. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

9. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

10. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

11. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

12. **RRTAC 82-3: The Alberta Government's Reclamation Research Program - 1981. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,499,525 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

13. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials (See RRTAC 92-4).

14. **RRTAC 83-2: The Alberta Government's Reclamation Research Program - 1982. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,536,142 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

15. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

16. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

17. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

18. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

19. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

20. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report describes the expenditure of $1,529,483 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

21. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

22. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. No longer available.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

23. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. No longer available.**

This report describes the expenditure of $1,320,516 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

24. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

25. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

26. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

27. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

28. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

29. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

30. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

31. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report describes the expenditure of $1,168,436 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

32. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

33. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

34. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

36. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report describes the expenditure of $1,186,000 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

37. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

38. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

39. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

40. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

41. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

42. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

43. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project.**
A. Maslowski-Schutze. 78 pp. $10.00

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

44. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. No longer available.**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

45. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

46. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

47. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. No longer available.**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

48. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

49. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

50. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. No longer available.**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

51. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

52. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

53. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

54. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. No longer available.**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

55. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

56. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

57. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

58. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

59. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

60. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. ISBN 0-7732-0878-X. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

61. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. ISBN 0-7732-0882-8. $10.00.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

62. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. No longer available.**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

63. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. No longer available.**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

64. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

65. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

66. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

67. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

68. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

69. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

70. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

71. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

72. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

73. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

74. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

75. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. No longer available.**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

76. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. ISBN 0-7732-0874-7. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

77. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. ISBN 0-7732-0876-3. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is not a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

78. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. ISBN 0-7732-0880-1. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

79. **RRTAC 92-1: Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta. M. Cotton and M.P. Sharma. 64 pp. ISBN 0-7732-0884-4. No longer available**

This report assesses the extent of sterilant use on oil and gas leases in Alberta, identifies some of the concerns related to reclamation of sterilant affected sites and the common methods for reclaiming these sites, and outlines the methods for sampling and analyzing soils from sterilant affected sites. The report also provides an outline of a research program to address issues raised by government and industry staff.

80. **RRTAC 92-2: Reclamation Research Annual Report - 1991. Reclamation Research Technical Advisory Committee. 55 pp. ISBN 0-7732-0888-7. No longer available.**

This report describes the expenditure of $485,065 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the five program areas, and describes the projects funded under each program. It also lists the 75 research reports that have been published to date.

81. **RRTAC 92-3: Proceedings of the Industry/Government Pipeline Reclamation Success Measurement Workshop. R.J. Mahnic and J.A. Toogood. 62 pp. ISBN 0-7732-0886-0. $5.00.**

This report presents the results of a workshop to identify the soil and vegetation parameters that should be used to assess reclamation success on pipelines in Alberta. Six soil parameters (topsoil admixing; topsoil replacement thickness; compaction; soil loss by erosion; texture; and salinity) and six vegetation parameters (plant density; species composition; ground cover; vigour; weeds/undesirable species; and rooting characteristics) were selected as most important. Working groups discussed these parameters and presented suggested methods for assessing them in the field.

82. **RRTAC 92-4: Oil Sands Soil Reconstruction Project Five Year Summary. HBT AGRA Limited. 109 pp. ISBN 0-7732-0875-5. $10.00**

This report documents a five year study of the effects of clay and peat amendments to oil sand tailings sand on survival and growth of trees and shrubs. Ten species (jack pine, white spruce, serviceberry, silverberry, buffaloberry, pin cherry, prickly/woods rose, Northwest poplar, green alder, and Bebb willow) were planted into tailings sand amended with three levels of peat and three levels of clay. The treatments were incorporated to a depth of 20 cm or 40 cm. Data are provided on plant survival and growth, root size and distribution, disease and small mammal damage, herbaceous cover, soil moisture, soil chemistry, and bulk density.

83. **RRTAC 92-5: A Computer Program to Simulate Groundwater Flow and Contaminant Transport in the Vicinity of Active and Reclaimed Strip Mines: A User's Guide. A.S. Crowe and F.W. Schwartz, SIMCO Groundwater Research Ltd. 104 pp. plus appendix. ISBN 0-7732-0877-1. NOTE: This report is only available from the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7 as ARC Information Series 119. The cost is $20.00 and the cheque must be made out to the Alberta Research Council.**

The manual describes a computer program that was developed to study the influence of coal strip mining on groundwater flow systems and to simulate the transport of generated contaminants, both spatially and in time, in the vicinity of a mine. All three phases of a strip mine can be simulated: the pre-mining regional groundwater flow system; the mining and reclamation phase; and, the post-mining water level readjustment phase. The model is sufficiently general to enable the user to specify virtually any type of geological conditions, mining scenario, and boundary conditions.

84. **RRTAC 92-6: Alberta Drilling Waste Sump Chemistry Study. Volume I: Report (Volume II: Appendices is only available through the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7. The cost is $15.00 and the cheque must be made out to the Alberta Research Council.). T.M. Macyk, S.A. Abboud and F.I. Nikiforuk, Alberta Research Council. 217 pp. ISBN 0-7732-0879-8. $10.00.**

This study synthesizes the data from sampling and analysis of the solids and liquids found in 128 drilling waste sumps across Alberta. Drilling waste types sampled included: 72 freshwater gel, 19 invert, 27 KCl, 2 NaCl, and 8 others. Data and statistics are tabulated by waste type, depth of the drill hole, and ERCB administrative region for both the solids and the liquids. Using preliminary loading limits developed by the government/industry Drilling Waste Review Committee, the report presents information on the volume and depth of waste that could be landspread, and the area required for landspreading. The oil and gas industry provided approximately $585,000 for the sampling and analysis phase of this study.

85. **RRTAC 93-1: Reclamation of Native Grasslands in Alberta: A Review of the Literature. D.S. Kerr, L.J. Morrison and K.E. Wilkinson, Environmental Management Associates. 205 pp. plus appendices. ISBN 0-7732-0881-X. $10.00.**

A review of the literature on native grassland reclamation was conducted to summarize the current state of knowledge on reclamation and restoration efforts within Alberta. The review is comprehensive, including an overview of the regulations and guidelines governing land use on native prairie; a description of the dominant grassland ecoregions in Alberta; a review of the common disturbance types, extent and biophysical effects of disturbance on native prairie within Alberta; a description of the factors which influence the degree of disturbance and reclamation; and examples of both natural and enhanced recovery of disturbed sites through the examination of selected case studies.

86. **RRTAC 93-2: Reclamation Research Annual Report - 1992. Reclamation Research Technical Advisory Committee. 56 pp. ISBN 0-7732-0883-6. $5.00.**

This report describes the expenditure of $474,705 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and the research strategies of the five programs, and describes the projects funded under each program. It also lists the 85 research reports that have been published to date.

87. **RRTAC 93-3: Catalogue of Technologies for Reducing the Environmental Impact of Fine Tailings from Oil Sand Processing. B.J. Fuhr, Alberta Research Council, D.E. Rose, Dereng Enterprises Ltd., and D. Taplin, Komex International Ltd. 63 pp. ISBN 0-7732-0885-2. $5.00.**

A catalogue containing 22 technologies for reducing the environmental impact of fine tailings derived from oil sands has been assembled. The report consists of an introduction to oil sand processing and fine tailings generation, a simple spreadsheet for comparing the technologies, and a process summary for each technology. The technologies were not evaluated for effectiveness. Rather, a detailed set of questions was prepared that highlights the environmentally-related information a proponent should have. These questions will help to form a basis for comparisons among the technologies.

88. **RRTAC 93-4: Organic Materials as Soil Amendments in Reclamation: A Review of the Literature. Land Resources Network Ltd. 228 pp. ISBN 0-7732-0887-9. $10.00**

A review of the literature was conducted to examine the effect of various organic materials when used as amendments to disturbed soil. Organic amendments reviewed included animal manures, crop residues, peat, wood wastes, sewage sludge, municipal yard waste, humates, vermicomposts, and spent mushroom composts. Their effects on soil chemistry, physical properties, and biology were examined. Application methods, costs, longevity of effects, and use in reclamation were also reviewed. Benefits and drawbacks of each were discussed.

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